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Management and Technical Procedures for Operation and Maintenance of Air Pollution Control Equipment

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16. ABSTRACT

This manual supplies agencies and industrial users with management and technical guidelines for effective operation and maintenance of air pollution control equipment. The manual covers four major topics. Section 1 discusses organization of maintenance operation, maintenance job planning and scheduling, maintenance work measurement, preventive maintenance, maintenance material control, budgets, and training. Sections 2 through 4 discuss the three major types of air pollution control equipment: baghouses, electrostatic precipitators, and scrubbers. Emphasis is placed on simplified startup, operating, and shutdown procedures. Routine inspection procedures are supplemented with detailed checklists. A general program is presented for troubleshooting air pollution control equipment. Case histories for a pulse-jet baghouse, dry and wet electrostatic precipitators, venturi scrubber, and packed tower are included in the appendix to provide the user with a sample program for improving equipment performance reliability. Section 5 discusses equipment and components common to all types of air pollution control equipment, such as hoods, ducts, fans, and stacks. Section 6 provides the details of the tools and equipment required to perform inspection and maintenance satisfactorily.

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MANAGEMENT AND TECHNICAL PROCEDURES FOR OPERATION AND MAINTENANCE OF AIR POLLUTION CONTROL EQUIPMENT

by

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Cincinnati, Ohio 45246

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REGIONAL OFFICE V
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SECTION 1

INTRODUCTION

1.1 BACKGROUND

Regardless of its type and function, processing or manufacturing equipment that is electric or mechanical requires service and maintenance to some degree, and air pollution control equipment is no exception. With the adoption of the Clean Air Act Amendments in 1970 and 1977, not only have the capital expenditures for this equipment grown exponentially, but the costs to operate and maintain it have also skyrocketed. To emphasize the importance of operation and maintenance (O&M), the Ninth Annual Report (December 1978) of the Council of Environmental Quality indicated that 1977 expenditure for O&M was 3.1 billion dollars. This figure includes both public and private sectors, exclusive of mobile sources. Projected costs for 1985 are 9.4 billion dollars, with cumulative costs from 1977 to 1985 estimated at 76.2 billion dollars. The cost of lost production, caused by defects and deterioration through wear and tear, is calculated at three to four times the O&M amount. By no means are these conditions inevitable; many can be averted or retarded, along with their costly consequences. Preventive maintenance is a means to this end.

Air pollution abatement equipment is purchased, operated, and maintained under conditions quite dissimilar to processing and manufacturing equipment. Unless the abatement equipment is being used for product recovery, it is procured because of government regulations. Besides requiring large capital expenditures, with the associated O&M costs, it produces no return on investment (ROI). In the absence of strong regulatory and managerial enforcement, there is a strong tendency to minimize O&M even if a quality piece of control equipment was purchased. In the event that a source is cited for an emissions violation, subsequent enforcement of the regulations could result in derating, curtailment, or even shutdown of the process equipment.

Following the initial startup period, the new abatement equipment is frequently neglected because of the overriding demands of production. The maintenance department thus finds itself with a rapidly deteriorating piece of equipment. Because government regulations required the procurement of the abatement equipment, it was probably purchased on a low bid basis, thereby resulting in an inferior quality product. In due course, the user blames the vendor for selling him inferior and poorly designed equipment, and the vendor blames the user for inadequate preventive maintenance. Both parties usually have valid arguments. It is under these conditions that air pollution control equipment is usually purchased and operated. The ultimate solution for both government and industry is for the abatement equipment to be considered an integral part of the process and treated with equal respect.

1.2 SCOPE OF THE REPORT

With the aforementioned costs and considerations surrounding the procurement, operation, and maintenance of air pollution abatement equipment, this report will supply agencies and industrial users with management and technical guidelines for effective operation and maintenance of air pollution control equipment. The report is divided into four major topics:

Section 2
Maintenance management of air pollution control equipment

Sections 3 through 5
Technical aspects of the design, operation, and maintenance of air pollution control equipment (baghouses, electrostatic precipitators, scrubbers)

Section 6
Technical aspects of the design, operation, and maintenance of items common to all air pollution control equipment

Section 7
Inspection, safety, and maintenance equipment

Section 2 includes discussions on organizing a maintenance operation, maintenance job planning and scheduling, maintenance work measurement, preventive maintenance (PM), maintenance material control, budgets, and training, emphasizing air pollution control equipment.

Sections 3 through 5 include discussions of the three major types of air pollution control equipment: baghouse, electrostatic precipitator (ESP), and scrubber. Emphasis is placed on simplified startup, operating, and shutdown procedures. Routine inspection procedures are supplemented with detailed checklists. A general program is presented for troubleshooting air pollution control equipment. Case histories for a pulse-jet baghouse, dry and wet electrostatic precipitators, venturi scrubber, and packed tower are included in the appendix to provide the user with a sample program for improving equipment performance reliability.

Section 6 discusses equipment and components that are common to all types of air pollution control equipment, such as hoods, ducts, fans, and stacks.

Section 7 provides the details of the tools and equipment required to satisfactorily perform inspections and maintenance.

The ultimate purpose of this report is to provide managerial and technical methods and procedures for the user of air pollution control equipment to maintain his equipment, service it on a periodic basis, and to keep it within emissions limitation and opacity standards. It will provide details for the hypothetical user, regardless of the type of equipment used or the type of maintenance performed.

It would not be possible in a work of this size to cover in detail every management and technical aspect of air pollution control equipment maintenance. An attempt has been made, however, to highlight and develop in appropriate detail the problems most commonly encountered.

SECTION 2

MAINTENANCE MANAGEMENT OF AIR POLLUTION CONTROL EQUIPMENT

2.1 DEFINITIONS

Within the scop of this report, a standard terminology will be used. In some cases, these definitions may not coincide with either national or international plant engineering standards, or with state or Federal guidelines:

Deterioration: Unfavorable and undesirable changes in the condition of any electrical or mechanical components, assemblies, or subassemblies.

Defects: The maximum amount of deterioration that could be tolerated.

Drift defect: Gradual development of defects.

Random defect: Sudden development of defects.

Maintenance: Actions that are performed to restore an item to an acceptable condition and, therefore, to enable it to continue to reach its required operating capacity. Note: The "acceptable condition" can be set by the organization executing the maintenance, and will probably vary from one company to another. (Maintenance should not necessarily be equated with any work undertaken by a maintenance worker).

Emergency maintenance: Maintenance activities that must be performed immediately, or in the near future, to avoid serious consequences.

Planned maintenance: Maintenance carried out in accordance with a well-devised plan.

Corrective maintenance: Maintenance specifically employed to restore equipment to its acceptable condition.

Preventive maintenance (PM): Maintenance carried out in accordance with a planned schedule to make sure that the equipment adheres to an acceptable standard. Unfortunately, the word "preventive" attracts attention to the apparent goal of the activity (prevention) instead of the activity itself (periodic/predetermined interval/planned schedule).

Breakdown: Any sudden unavoidable failure of air pollution control equipment or process equipment to operate in a normal and usual manner.

Excess emissions: An emission rate that exceeds any applicable standard of performance prescribed by Federal, state, or local rules, or that violates any condition in a permit.

Malfunction: Any failure of air pollution control equipment or process equipment to operate in a normal and usual manner that is caused entirely, or in part, by poor maintenance, careless operation, or other preventable upset condition or preventable process equipment failure.

2.2 THE MAINTENANCE ORGANIZATION

The single most important ingredient in effective maintenance management is identification of qualified individuals to effect and implement the maintenance function. Although plant management is usually well aware of the need for maintenance management, few programs are operating as they were intended to operate. Because nearly all maintenance activities are human activities, and are, for the most part, controlled by those individuals doing the work, even the most explicit inspection checklists and well-written procedures (including this report) will not achieve the desired goal unless the persons performing the work have the willingness and integrity to execute the defined tasks.

In manufacturing operation, performance output can be measured through careful production control systems. A malfunction of the system is immediately apparent, and often results in poor production quality, reduced product output, and failure to meet a delivery date. There is no reason to assume that maintenance operations for air pollution control equipment cannot similarly be formalized. The job or task being done, however, is usually not as obvious, and thus more attention must be paid to the routine requirements of the maintenance control system.

The O&M of air pollution control equipment must generally be included within the framework of an existing in-house program. Thus management must, as it may appear, intrude upon an already overworked, understaffed, and underfunded maintenance department to integrate the new functions into the program. The equipment is typically viewed with (a) suspicion, (b) caution, and (c) annoyance; occasionally it is treated as important and primary to the overall manufacturing process because its breakdown or malfunction could dictate the level of production for the plant.

To effect a viable maintenance program, a support organization must be available. A typical organizational chart for a small- or medium-sized plant is shown in Figure 1.

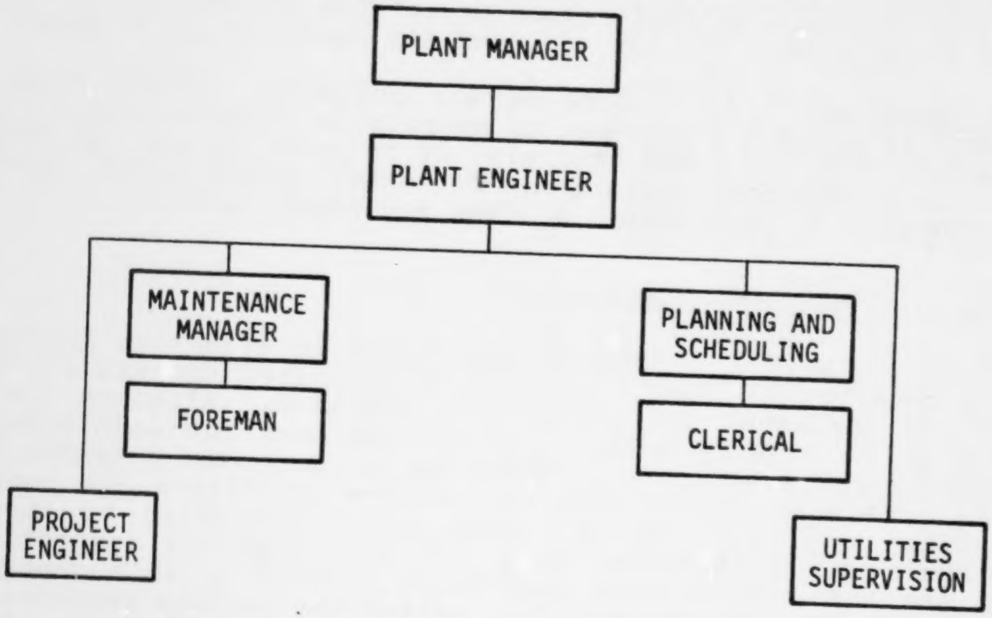


Figure 1. Typical organizational chart for a small- or medium-sized plant.

The plant manager's primary function is to operate the plant for maximum profits and minimum costs. The plant engineer has the responsibility to see that the plant operates effectively and continues to produce goods. He is often also responsible for environmental matters: noise, OSHA regulations, in-plant fumes, dust and odors, air emissions, water effluents, permit applications, and codes and standards. To meet this immense responsibility, which includes the performance of air pollution control equipment, he must create a supporting organization around him.

As indicated in Figure 1, the plant engineer usually finds it necessary to delegate the maintenance function to an individual who, for all practical purposes, will be called the maintenance manager and may, in fact, be an engineer. The maintenance manager must have a sound knowledge of manufacturing machines and adapt himself to include air pollution control equipment. The maintenance manager must also possess management abilities, since most of his working hours are spent in getting the job done through people. His most critical subordinate is his foreman, whose job it is to see that the workers are properly instructed and competent to maintain the plant. The foreman is the vital link between management and job execution. He must know his workers and their respective capabilities to perform certain jobs.

Throughout this discussion, the emphasis has been directed towards people and how they could contribute to equipment performance. Prior to equipment operation, however, in-house support, such as engineering and purchasing, becomes involved. It has proven to be extremely beneficial to the performance of air pollution control equipment to involve from the outset those individuals who can contribute to its success--engineers, line workers, and others. Sudden changes in organization and operations due to equipment acquisition can be interpreted by employees as actions to tighten management controls, produce more work, and hence reduce job satisfaction.

The installation and operation of air pollution control equipment may precipitate the redesign or modification of either a formal or informal maintenance management information system. Should this be the case, it is incumbent on the maintenance manager to:

Clearly define and identify the objectives of the system

Determine effective methods of work planning and scheduling

Determine methods of measuring and appraising maintenance performance

Determine the personnel required

Adopt budget and financial control procedures

Although these are some ingredients of a maintenance management system, it should not be construed as a magic formula that will provide the best maintenance organization for a particular plant.

2.3 MAINTENANCE PLANNING, SCHEDULING, AND WORK MEASUREMENT

2.3.1 Planning and Scheduling

The function of maintenance planning and scheduling is as follows:

Minimization of idle time. (Only 30 to 40 percent of a worker's time is spent using his tools; the remainder is spent traveling to and from the job, acquiring materials and supplies, waiting for other phases to be completed and for production equipment to be shut down.)

Maximizing the efficient use of worktime, materials, and equipment

Operating at a level that is responsive to the needs of manufacturing production

Before a maintenance work order is scheduled to be executed, it must be planned according to its scope, priority, sequence of performance, methods and materials to be used, safety requirements, manpower, time estimate, and site availability. The work order form, which usually emanates from the production department, is the mechanism that requests work to be performed. It must include sufficient information for the planner and scheduler to determine the resources needed for the project. The replacements of bags, solenoid valves, scrubber nozzles, and ventilation filters for ESP insulator compartments are simple requests that can be implemented with little additional explanation. More complicated situations, such as troubleshooting baghouse high pressure drops, require greater effort.

The individual who plans and schedules the work order must be familiar not only with the productive system, but also with the major components of the air pollution control equipment (i.e. pumps, blowers, conveyors). He should perform site visits to make periodic equipment reviews. Because of the nature of maintenance, this person must be able to modify plans and schedules frequently, and see that adequate materials and spare parts are available to execute the work order. He should not be restricted to the way things have always been done: new procedures, standards, and equipment may be appropriate.

The time for the work to be performed may be scheduled while the equipment is operating or shut down. It is desirable to perform the work during regular equipment shutdown, with priority work being scheduled first. When work schedules must be changed, substitute work orders may be necessary, thus maximizing available resources and hence the requirement for backlog work orders. Although there are scheduling techniques available to maintenance management, such as the Gantt Charts and Critical Path Methods (CPM), they will not be discussed in this report.

Safety provisions must be planned should the work order require it. Special clothing (goggles, masks, boots, gloves), fire and electrical protection, ventilation, barricades, and lights must be specified. As an example, personnel performing bag changes must use respirators, hard hats, and goggles. Should it be necessary to enter any type of air pollution control equipment, the worker must be accompanied by another individual.

2.3.2 Work Measurement

Regardless of the type or extent of the work being performed by an individual or team, or the materials used, a method to estimate costs accurately must be available to the maintenance manager. A method of measurement is needed as a basis for product pricing and costing, improvement of worker effectiveness, more efficient manpower utilization, reduced costs of new and/or improved facilities, efficient scheduling of preventive maintenance, and identification of worker education requirements.

With the ultimate goal of reducing costs and improving quality, the methods that maintenance management can use to measure work are experience, historical information, and standard data. For example, experience has taught that 12 bags require replacement every month. Therefore, once a month the manager can estimate the cost, manpower, and materials to be devoted to a specific task. The primary disadvantage of this form of work measurement is that periods of inefficiency and ineptitude are not usually identified since "experience" has taught maintenance management that "it has always been done 'that way'." With new air pollution control equipment, no experience is available to estimate the time required for preventive maintenance and repair.

If a particular job has been performed numerous times, historical data may be available to estimate the average performance time. If the work is being performed in a manner satisfactory to management, this may be considered standard.

2.4 PREVENTIVE MAINTENANCE

2.4.1 Benefits of Preventive Maintenance

In addition to maintaining compliance with air pollution emission regulations, an air pollution control equipment preventive maintenance program will enable the user to accomplish the following:

Assure that production levels are not affected

Minimize maintenance cost

Maximize scheduled shutdown periods

Significantly reduce equipment breakdowns, downtime, and malfunction

Extend equipment life

Reduce emergency repairs

Reduce overtime

Reduce overall maintenance and attendant repair costs

Minimize spare parts inventory

The more a plant is oriented toward capital equipment, the more it can reap the benefits of a preventive maintenance program. This is true because this type of plant requires more maintenance than does a labor-intensive plant.

By definition, preventive maintenance refers to activities that fight defects in existing equipment without changing the design of the equipment. In the field of air pollution control, however, additional onsite and in-house engineering is often performed on the equipment to reduce user costs of operation and maintenance. Vendor unfamiliarity with the process, or inadequate preventive maintenance, will often necessitate equipment modifications and redesign to accommodate actual operating conditions.

2.4.2 Reasons for Minimum Preventive Maintenance

In spite of the tangible and intangible benefits of preventive maintenance, air pollution control equipment nonetheless remains neglected. Typical reasons given for minimum maintenance are summarized as follows:

Attention and effort are better spent on process equipment.

Pollution equipment and associated components are of poor quality because they were purchased on a low bid basis.

Plant personnel are not inclined to maintain equipment that is dirty, dusty, potentially hazardous, and inaccessible for service.

Equipment is located outside the plant building and therefore often goes unnoticed and unattended until problems exist.

Defects and obsolescence of the electric and mechanical components are inevitable occurrences.

Plant personnel are unwilling to stock replacement parts, supplies, and accessories.

There are not enough maintenance personnel and funds.

Corporate engineering incorrectly specified equipment and should have consulted the plant.

No one individual is willing to manage and coordinate the maintenance function.

Insufficient technical knowledge is present to diagnose and troubleshoot problems.

Management views preventive maintenance as nothing more than lubrication and cleaning on a scheduled basis.

The position of management is typically not to spend money unless the return on investment can be realized in the near future. The acquisition of additional skilled workers, materials, spare parts, and power tools is looked upon with great caution and skepticism, especially since the ROI is not likely to be felt for as long as 2 years.

A PM program must be appropriately introduced to plant management if it is to be enlarged and expanded. At this juncture, the attitude of plant management to maintenance could be: "We bought it, now you take care of it." The task of selling the preventive maintenance program to management should be well thought out; especially regarding costs and advantages. Some of the elements critical to selling the program are described below:

Identify the individuals in management and operations who have the authority to make decisions, either directly or indirectly. (Do not avoid those persons who you think will not be responsive.)

Discuss program with maintenance workers and supervisors, because their cooperation and enthusiasm are essential.

Define a means to evaluate the effectiveness of the program.

Estimate project cost savings, man-hours, materials, and similar items.

Goals and objectives should be realistic; therefore, the scope of the program should be small before a more comprehensive one is planned.

Clearly define the equipment and components that must be inspected and maintained. (Equipment instruction manuals must be supplemented by worker information.)

Compile checklists that include not only items to be inspected or maintained, but also the sequence of events and operations.

Estimate the frequency of inspection.

These ingredients, plus a presentation of the overall benefits of the program (as given in 2.4.1), are essential for selling the PM program. If management wants to streamline the proposed program, it is generally advisable to adhere to their requests in order to initiate the program. After a given period of time, with the necessary appraisals of performance, the program will probably need expansion and modification. By its nature, preventive maintenance is dynamic and constantly in flux, and close monitoring is needed to see that management and operations requirements are being fulfilled.

The primary considerations in having the preventive maintenance program approved are financial ones. When the program is developed, budgets must be estimated with the awareness that maintenance competes with production for funds. The production budget is usually based on demand for services, and successful competition with production requires the use of a method to calculate ROI.

2.5 MAINTENANCE PERFORMANCE EVALUATION

The resources that are available to maintenance are manpower, material, and equipment. Of the three, the most difficult to control is manpower, as reflected in wage rates. Labor control can easily be effected through careful administration of how, when, and where the work is to be performed. The simplest and most direct method to measure manpower production is to compare the man-hours actually consumed to perform a particular task with that originally estimated. Significant and frequent deviations from the estimates require investigation.

The maintenance report is the most important mechanism for effective maintenance control, i.e., control of labor productivity. It should contain such ingredients as the skills used to effect the work, associated labor costs, and comparison of actual vs. estimated man-hours. It may also contain a comparison of the maintenance costs for a particular period or job with comparable costs derived from some base period. Although they are indicators, and not maintenance control functions, open work orders help management monitor the progress of the maintenance function. A comparison between man-hours spent on planned work and those on unplanned maintenance, and the ability to forecast the completion of jobs on schedule, are additional maintenance control indicators.

As an example of the use of some of these controls and indicators, a particular baghouse was having frequent bag failures; the cause was attributed to hot cinders being carried to the bags. Excessive man-hours and bag replacement were obvious consequences. Emergency baghouse shutdowns, coupled with several community complaints, forced management to find a way to solve the problem. Spark arrestors were subsequently installed and the ROI realized within 1 year. The motivation to install equipment was primarily one of cost savings; air pollution abatement was secondary.

2.6 SPARE PARTS AND MATERIAL CONTROL

The introduction of air pollution control equipment (or any equipment) to a plant requires the purchase of spare parts and supplies. The types, quality, and costs incurred are but a few of the considerations to be reviewed. The spare parts needed are those typically associated with moving and rotating parts.

At the outset, critical spare parts should be identified. This information is usually available from the equipment manufacturer. With equipment use, plant experience is acquired thereby further identifying spare parts requirements. In this regard, a critical part is one that could slow down or abort production. For instance, a clogged scribber nozzle may affect emissions somewhat, but substantial mist eliminator buildup would diminish system flow rate. An available spare set of mist eliminator media would immediately alleviate the problem, thus minimizing system shutdown.

Replacement bags, nozzles, gaskets, hose clamps, and other items that are changed frequently should be in ample supply. The storeroom personnel must be responsible for this supply and must maintain an inventory information system to provide lead-time to procure replacements.

The materials and spare parts inventory for air pollution control equipment may vary according to season, plant shutdown, and process modification. For instance, during winter months the entrained moisture in compressed air lines to pulse-jet baghouse valves may freeze and cause unit disfunction. Excessive demand for replacement valves and bags may occur, necessitating rebagging and process shutdown.

Suppliers in remote locations and long leadtime items are problems of great concern to maintenance. Noncritical items must be procured with sufficient leadtime to avoid emergency situations. It is, however, difficult to justify ordering expensive supplies and equipment when there is only a possibility that they may be needed. An example is a spare high-horsepower motor for a venturi scrubber fan.

Cost considerations often overlooked are those incurred to store spare parts and materials. Space, recordkeeping, and additional taxes and insurance are also significant contributions to the overall maintenance cost picture. Inventory costs can be reduced if replacement items can be procured locally.

2.7 MAINTENANCE BUDGETS

A financial plan for the procurement of air pollution control equipment is usually thoroughly prepared. Annual operation and maintenance budgets for air pollution control equipment are estimated at 10 to 12 percent of the capital equipment cost. This guideline is reasonably accurate, but more of the details pertinent to maintenance supplies, labor, and equipment should be analyzed. The most important element of the maintenance budget is the man-hour estimate. Man-hours may be further subdivided into such categories as inspection, lubrication, particular process equipment, and air pollution control equipment. A major advantage of this method of budgeting is expenditure visibility, i.e., cost control and the ability to monitor the flow of funds.

In addition to manpower and material budgets, the procurement of capital equipment (high-power industrial vacuum cleaners, for example) should be included in each annual budget. Since capital equipment programs can be expressed in terms of ROI, management is more likely to approve these budget requests than others.

2.8 TRAINING AND EDUCATION

Regardless of the type of equipment, a well-planned training and education program is crucial to production improvement and reliable equipment operation. Management usually resists these programs unless excessive operating problems arise. In the case of operating and maintaining air pollution control equipment, even less attention is given to training. Maintenance management often thinks that the line workers will acquire the necessary knowledge "on the job."

Besides the maintenance workers, the personnel who should be familiar with the operation and maintenance of air pollution control equipment are supervisors, planners, and schedulers. At startup, the operation and maintenance department should see that the original equipment manufacturers provide a suitable training program, supported by the necessary instruction manuals for service and maintenance. For intensive training, several equipment manufacturers have prepared video tapes in support of classroom instruction.

Instruction at the training sessions should also be given by the manufacturers of the subassembly components and systems. For example, the supplier of an electrostatic precipitator should include the manufacturers of the transformer/rectifier and ash handling systems at the training sessions. If the air pollution control equipment contains opacity measurement capability, a representative from the instrumentation manufacturer should also be present.

The training program should be devised by both user and equipment manufacturer. The user must identify the personnel (skilled workers, engineers) who will have some responsibility for the equipment, and the manufacturers must gear their presentation to this audience.

Although this approach appears to be elaborate, it is the only reasonable way to guarantee that the equipment will be operated and maintained satisfactorily. Unless a training program is defined during original contractual agreement, it usually does not fall within the framework of the original equipment capital cost. In this case, plant management may be reluctant to fund it at a later date.

Air pollution control equipment usually develops problems before management becomes more conscientious about the need for training and preventive maintenance. If management does not endorse an extensive training program, it is incumbent on operation and maintenance management to measure and evaluate the long-range outcome of the training program, especially with respect to ROI.

Another consideration in developing a training program is the amount and complexity of the abatement equipment. A small plant may have only one piece of equipment, whereas a large one could have numerous types and amounts.

2.9 CONTRACT MAINTENANCE SERVICES

In recent years, the concept of contract management has become more and more acceptable, especially in new plants. Plants use contract maintenance to buy know-how and reduce costs, while still retaining flexibility. In-house maintenance functions, however, cannot be eliminated. The benefits of contract maintenance, with emphasis on air pollution control equipment, are given below:

> Plant personnel do not have to be thoroughly trained in equipment maintenance, thus allowing them to devote their time to process equipment.
>
> Technological troubleshooting and problem diagnosis are not usually in-house resources.
>
> Plant personnel do not have the knowledge to improve equipment performance.
>
> Plant personnel may lack awareness of alternative supplies and suppliers.
>
> Expenditures for larger crews, repair facilities, tools, and measurement instruments are reduced.
>
> Previous experience on similar equipment and applications can be used.
>
> Interpretations of causes of component failure can be provided.
>
> Contract maintenance programs are more effectively regulated and administered than are in-house programs.
>
> Dirty and hazardous jobs do not have to be performed by plant personnel.
>
> Fluctuating workloads due to startup and seasonal variations can easily be handled.

2.10 VENDOR CONTRIBUTION TO POOR EQUIPMENT PERFORMANCE

Even the most explicit procedures, guidelines, and inspection checklists will not achieve desired goals unless the person or organization performing the work has willingness, motivation, and resources to do the job. Because nearly all operating and maintenance activities are human activities, they are controlled by those individuals doing the work. On the other hand, the reader should not assume that the users of air pollution control equipment are solely responsible for poor equipment performance. Vendors also contribute in the following ways:

> Misapplication of equipment due to unfamiliarity with contaminants and process parameters
>
> A highly competitive marketplace, resulting in cost reduction methods that often have a negative effect on product reliability and component quality
>
> Inadequate and inept design for ease of maintenance (i.e., access doors, blind flanges, internal catwalks, component accessibility)
>
> Insufficient performance monitoring instrumentation
>
> Improperly located pressure taps, leading to dust buildup and clogged air lines.
>
> Insufficient stock and inventory of component replacements.
>
> Primary interest in product sales (flange to flange), not total system design and installation.
>
> New equipment designs that are inadequately tested and evaluated in the field

2.11 CONCLUSIONS

The installation and operation of air pollution control equipment covers a wide range of disciplines, from management to technical aspects, plant managers to skilled workers, emergency to preventive maintenance, and budgets to training. Much of the attention in this field has been devoted to the technical phases, not the managerial and administrative. The reader with sufficient background should now be familiar with the overall scope of the management aspect of the operation and maintenance of air pollution control equipment.

SECTION 3

TECHNICAL ASPECTS OF THE DESIGN, OPERATION, AND MAINTENANCE OF BAGHOUSES

3.1 BACKGROUND

This section of the report provides the user of baghouses with sufficient guidelines and procedures to enable him to operate, service, and maintain this equipment in order to comply with air pollution emissions regulations. It provides details on special equipment components; procedures for startup, routine operation, shutdown, inspection, and maintenance; and recommendations for spare parts and materials. A sample troubleshooting case history is presented in Appendix A to give the user a program for improving equipment performance reliability. The principles of air pollution control equipment and mechanisms of contaminant collection will be discussed only in terms of operation and maintenance.

3.2 BAGHOUSE COMPONENTS AND OPERATIONAL PARAMETERS

Baghouses are categorized according to their cleaning mechanisms: shaker, pulse jet, and reverse air. The ingredients common to all types of baghouses are: air-to-cloth ratio (filter rate), pressure drop, cleaning mechanism, frequency of cleaning, filter cloth characteristics, number of baghouse modules, materials of construction, and method of handling the collected contaminant.

The discussion that follows describes the engineering principles and comments on components that cause problems in equipment operation and maintenance.

3.2.1 Air-to-Cloth Ratio (Filter Rate)

The quantity of gas (acfm) passing through a given area (ft^2) of filter cloth is defined as the air-to-cloth ratio, filter rate, or superficial face velocity. Units for this parameter are cubic feet per minute per square foot, or feet per minute. Physically, the air-to-cloth ratio represents the average velocity with which the gas passes through the cloth without regard to the fact that much of the area is occupied by fibers. For this reason, the term "superficial face velocity" is often used.

Depending on the type of fabric and cleaning method, fabric filters can operate at air-to-cloth ratios of 15:1 and less. Upon startup with new and clean filter media, the pressure loss may be less than 0.5 in. H_2O. After initial operation (seasoning or conditioning), the pressure loss may approach 2 to 3 in. H_2O. At some time, the collected particulates (filter cake) and cloth must be cleaned, by one or a combination of mechanisms, to return the cloth to a significantly lower pressure loss. Typical air-to-cloth ratio for shaker and reverse air baghouses can range from <1:1 to 4:1 with woven filter media. Pulse-jet cleaning can use 5:1 to 15:1 air-to-cloth ratios with felted filter media.

The air-to-cloth ratio is a calculated number used for design and discussion purposes, and the ratio should not be assumed to exist throughout the baghouse media. For instance, the gas flow entering the baghouse may not be uniformly distributed and may be channeled in a preferential direction, resulting in a higher ratio in one section of the baghouse than in another. This problem may be overcome by providing turning vanes, flow splitters, and baffle plates.

From an aerodynamic point of view, the baghouse does not approach, or even come close to, an ideal geometric shape for gas flow. It should also not be assumed that all particulate follows the air streamlines in the baghouse. Gravity and other forces can cause particulates to digress from the streamlines, resulting in more particulate being filtered in one portion of the baghouse than another. Particulates measuring 5 μm or less, however, will follow the air streamlines and behave similarly to gas molecules.

3.2.2 Pressure Drop

The resistance to airflow (pressure drop) provided by a clean filter cloth is determined by the configuration and characteristics of the cloth and filtering velocity. One of the characteristics of clean fabrics frequently specified is the permeability, which is defined as the air volume (ft^3/min) that will pass through a square foot (ft^2) of filter media with a pressure differential of 0.5 in. H_2O. According to the type of fabric (yarn, weave, weight, etc.), the permeability could range from 15 to 100. This parameter is useful only in comparing one type of media with another.

In normal filter operation, the pressure loss is primarily attributed to the dust filter cake and cloth-entrapped particles, with a small portion of the pressure drop due to the cloth alone. Other than collection efficiency, the primary consideration in maintaining normal operating pressure drop is the energy cost to drive the air-moving blower: the higher the pressure drop, the more energy consumed. Continuous operation at high pressure drops also seriously weakens the filter integrity and structure. In an attempt to alleviate some of this high pressure drop, much attention has been given to the cloth characteristics (fiber diameter, fiber construction, porosity, cloth finishes, backings, coatings).

Although the resistance to the cloth filter and dust cake cannot be separated from the total resistance of the exhaust system, the operating characteristics of the exhaust blower and the duct resistance will determine the overall baghouse resistance. If possible, the user of the equipment should obtain information from the vendor regarding the pressure losses incurred because of the system ductwork, without bags being installed. This information may be valuable when comparing several equipment designs, because duct pressure drop does not contribute to filtration, only energy consumption.

Typical operating pressures, according to the application, can vary from 3 to 10 in. H_2O. As a rule of thumb, the pressure drop squares as air-to-cloth ratio (velocity) doubles. Attempts to increase the blower flow rate to exhaust contaminant more rapidly will seriously affect system pressure drop. By increasing the intensity or frequency of cleaning, it is possible to reduce pressure drops to levels approaching those of the clean fabrics. If this concept is carried too far, however, the collection efficiency may be adversely affected by damaging the fabric and consuming additional costs in driving the cleaning mechanism. The selection of an operating pressure loss is a matter of trade-offs, and may not necessarily conform to original design values. It is obvious, therefore, that monitoring the pressure drop across the baghouse is the single most important parameter indicating system performance.

3.2.3 General Design

The basic difference between one generic type of baghouse and another is the cleaning mechanism (shaker, reverse air, pulse jet). There are, however, common components for each and the following remarks will thus apply regardless of cleaning mechanism.

The baghouse casing is usually fabricated of light-gauge mild steel, and may be insulated to prevent temperature drops during operation. In applications handling abrasive materials or corrosive gases, a lining of corrosion-resistant material may be necessary. The filter bags within the housing are mounted to a tube sheet with hose, ring, or spring-loaded clamps. The clamps are mounted at the bottom on shaker and reverse air baghouses, at the top on pulse jet baghouses. The replacement of bags having hose clamps, which is extremely time consuming, is prevalent in older applications. Quick disconnect clamps and steel snap rings sewn into shaker bag cuffs are being specified more often.

The particulate-laden gas is usually introduced into the upper portion of the hopper. This allows the entering gas velocity to be reduced suddenly, thereby enabling the coarse particles to settle directly into the hopper. The finer particles, along with the gas, pass upward to the fabric filters (typically cylindrically shaped). According to the generic type of baghouse, filtration may occur on either the inner or outer surfaces of the bag. The cleaned gas is subsequently passed to a plenum before being discharged into a common manifold. As the amount of collected dust accumulates, the thickness of the filter cake also increases on the bags, thus producing a corresponding increase in the pressure drop across the collector. Periodically, either with a programmed timer or by monitoring the pressure loss with a differential pressure switch, the collector will go into its cleaning cycle.

The proper installation of bags with accessory hardware is one of the most important aspects of baghouse performance. The intention of the manufacturer is to provide efficient bag arrangement with proper bag clearances. The most common type of arrangement is bags that form straight rows. Sufficient clearance between bags avoids the possibility of rubbing, and specifications for tensioning should be provided by the manufacturer.

The most prevalent problem in baghouse design, regardless of type, is ease of access to bags for maintenance. Cost considerations often result in walkways, internal ladders, and access doors being omitted. Walkways between banks of bags must be provided; if the bags are long, catwalks are needed at the top and bottom of the bags. The manufacturer often designs the housing so that it is impossible to reach bags beyond an arm's length. A walkway should be provided around the bags to make them easily accessible. Top access doors are also necessary for proper inspection and bag maintenance.

3.2.4 Cleaning Mechanism

Shaker--

A baghouse with mechanical shaking consists of a housing divided into an upper and lower portion by the tube sheet. The upper portion usually contains woven fabric tubular bags, and the lower contains pyramidal hoppers, each with its own valve or with a long, trough-type hopper emptied by a sealed screw conveyor. The upper ends of the bags (which are flexibly mounted, often from a common support structure) are shaken by mechanical or pneumatic means. During cleaning, the shaking dislodges the filter cake from the inner surface of the bag and causes the cake to fall into the hopper. The shaking energy is transmitted most effectively next to the shaker bars and diminishes gradually to the thimble. Hence, occasions may arise in which the bags are cleaner at the top than at the bottom.

Upon conclusion of the cleaning cycle (1 or 2 minutes per hour; 1 to 5 cycles per second; amplitude up to 2 inches; 10 to 100 cycles) the damper opens, thereby returning the compartment or system to the filtering mode. In large systems, individual compartments are cleaned one at a time to keep the pressure loss across the collector at a nominal value.

The mechanical shaker mechanism consists of an electric motor coupled to a cam or eccentric, which translates the rotary motion of the motor into an oscillation through a connecting rod assembly. Bags may be shaken horizontally or vertically. The shaker motor drives an eccentric crankshaft via pulley belts to the frame from which the bags are hung. A pillow block bearing supports the crank shaft on one end of the shaker assembly and a shaker hanger on the other. Good design practice has the shaker mechanism mounted outside the baghouse housing for ease of maintenance, lubrication, and inspection.

No inflating pressure is permitted within the bags during shaking, because such a condition would impede fabric movement and hinder cake release. Butterfly and guillotine dampers, unless sealed properly, could contribute to air leakage and bag inflation; poppet valves are therefore recommended. Bag tension is also critical to proper cleaning. For instance, a 9-ft, seamed bag will move approximately 3 in. off the center line during shaking; longer bags will move somewhat more, and seamless bags require less movement.

The following situations could directly affect bag cleaning performance while operating shaker baghouses:

As a result of housing deformity, either from heat stress warpage, poor fabrication, or installation, bags are stretched or collapsed.

Housing deformity, with its associated dimensional changes, produces excessive wear on shaker assembly (crankshaft becomes misaligned and produces excessive wear on bearings and shaker hanger).

Dimensions of replacement bags may not coincide with the actual dimensions.

The bags are fastened to the shaker bars by various means. An older method consists of attaching the bag to a steel disc or cap (disposable caps are available) from which a threaded bolt is coupled to a shaker bar. A newer design consists of a sewn loop placed over a J-hook. Another fastening method consists of sewing the end of the bag into a flat strap, which is looped back and forth over a special hanger.

During cleaning, the pressure across the entire baghouse may increase somewhat. This increase usually occurs when modules or sections are isolated to allow for cleaning; overall performance is not usually affected.

Reverse Air--

This baghouse has a configuration similar to that of the shaker. The dirty gas can be passed through a single inlet into the trough-type hopper, or through a common inlet manifold that serves many pyramidal hoppers. Each tubular bag is clamped to a thimble at its lower end and to a flexibly mounted cap at the upper end. Filtration occurs from the inside of the tube to the outside.

During the cleaning cycle, a valve at the compartment outlet is closed. Simultaneously, a small air-vent valve is opened, allowing atmospheric air to rush in and collapse the bags. The air rushes in because the housing is under negative pressure. According to the cleaning requirements, a secondary blower providing the reverse air may be necessary.

Bag collapse breaks the filter cake and allows it to drop into the hopper. The reverse airflow is maintained by the suction through the common inlet manifold, which remains open. Upon conclusion of the cleaning cycle, the valve is opened, and the air vent and/or secondary blower is closed. Individual compartments are cleaned one at a time on a predetermined schedule activated by a programmer or by a monitoring of the draft loss.

Some filter tubes are equipped with rings spaced at given intervals along their vertical height. When the air is reversed, the bags collapse inward, but the rings prevent the cloth from rubbing against itself and permit the cake to fall without interference.

Pulse Jet--

Like the shaker, the pulse-jet baghouse is divided into an upper and lower portion by a tube sheet. The gas is usually introduced to the lower part of the housing, often through the hopper. The hopper serves as a settling chamber and allows large particles to be removed without needing to be filtered.

The gas flow is directed upward and around the cylindrical filter tubes and then through the filters from the outside direction. In contrast to the shaker, the filter cake is built up from the outside, not the inside. The cleaned gas passes upward through the tube sheet and out the outlet manifold.

The bags are cleaned periodically when sets of compressed air jets are actuated, blowing air at high pressure through the individual tubes. This flow is superimposed on the system flow. The filter bags are fabricated from felted media and supported by a wire cage or retainer. A venturi-shaped nozzle is often provided to improve the efficiency of the air pulse. The force of the pulse jet snaps the bag outward, thereby partially dislodging the accumulated filter cake. The system flow then snaps the bag onto the retainer and completes the cleaning.

The cleaning pulse usually cleans several bags in a row at one time. This procedure occurs through sets of manifolds and is controlled by a timer that activates a solenoid and diaphragm valve that releases the air pressure provided by a compressor. The dislodged contaminant falls to a hopper and is disposed of by an airlock, screw conveyor, or by pneumatic means. A variation in pulse cleaning design is the compartment or plenum pulse. In this case, an entire compartment is subjected to the cleaning pulse instead of a row of bags as in the pulse-jet situation.

Although other baghouse designs are available, the individual cleaning mechanisms are similar and may be used in conjunction with one another for more effective cleaning. According to the application and manufacturer, the filter configuration may range from an envelope shape to a disposable filter cartridge, the most common type being the cylindrical filter.

3.3 BAGHOUSE OPERATION AND MAINTENANCE

For a baghouse operation and maintenance program to be highly effective, a logical sequence of events should occur. Guidelines to be followed before startup and inspection are given below along with routine startup, operating, and shutdown procedures. The scope of the inspection procedure varies according to whether the unit is operating or shut down. When the unit is shut down, the condition of bags and hoppers can be viewed. The unit is otherwise inaccessible, with only such parameters as operating pressure and temperature and external cleaning and dust handling system components open to inspection.

3.3.1 Pre-Startup Inspection

If a new baghouse has been installed, or if one has undergone internal service and maintenance, it must be thoroughly inspected before it is "buttoned up." The inspection should include the following steps:

Remove such debris as nuts, bolts, tools, welding rods, and other items that may become airborne and behave as projectiles, puncturing bags or getting caught in operating mechanisms.

Remove all contaminant and inspect the hoppers for leaks and debris.

If single bags were replaced, inspect adjacent ones for damage.

Check bag connection and tension.

If entire unit was rebagged, check again after a few hours of operation.

Inspect walls for cracked, chipped coatings.

Inspect instrument monitoring locations, especially pressure taps.

Check valve seals on inlet and outlet ducts.

If possible before the unit is buttoned up, operate the various components to check their operation. It may be feasible to perform this work while workers are in the unit. If not, the unit should be closed up, operated without flow, and then shut down and inspected again.

3.3.2 Routine Startup

One of the most important items to consider in starting up a baghouse is the condition of the process air. If the air is moist, it is necessary to preheat the baghouse to avoid condensation, especially on the bags. Ideally, purging the system with warm, dry air will abort this problem; however, applications may arise where hot, clean air may not be available because by virtue of being hot it may already contain contaminants. In this case, external means of preheating are recommended, such as strip heaters. Even if the baghouse is insulated and out of service for only several hours, preheat may be required.

The outline procedure given below for routine startup can be used for shakers, reverse-air, and pulse-jet units.

1. Secure doors and hatches and notify personnel of startup.
2. Operate material handling system (airlocks, screw conveyors, etc.).

3. Open bypass dampers to allow hot, "clean" air to enter system for preheat.

4. Before starting blower, verify zero settings on monitoring instrumentation.

5. Start blower.

6. Engage cleaning circuit.

7. Record data from monitoring instrumentation (fan motor amperage and voltage, temperature and pressures).

8. Allow contaminant to pass baghouse and note and changes in monitoring data.

3.3.3 Routine Inspection and Maintenance During Operation

During routine operation, an inspection procedure recording baghouse operational data should be used. A sample of a routine daily inspection report for a shaker baghouse is provided in Figure 2. This document may be used to give the maintenance department a continuous record of system performance. The two columns headed "CHECKED" are to be filled in by the inspector to verify that he observed the condition of the component. The column "REQ. ATTN." is provided to alert maintenance personnel that a problem exists. In addition to the inspection, a maintenance checklist for a shaker mechanism is given in Figure 3. Figure 4 provides an inspection report for a pulse-jet baghouse.

3.3.4 Routine Shutdown

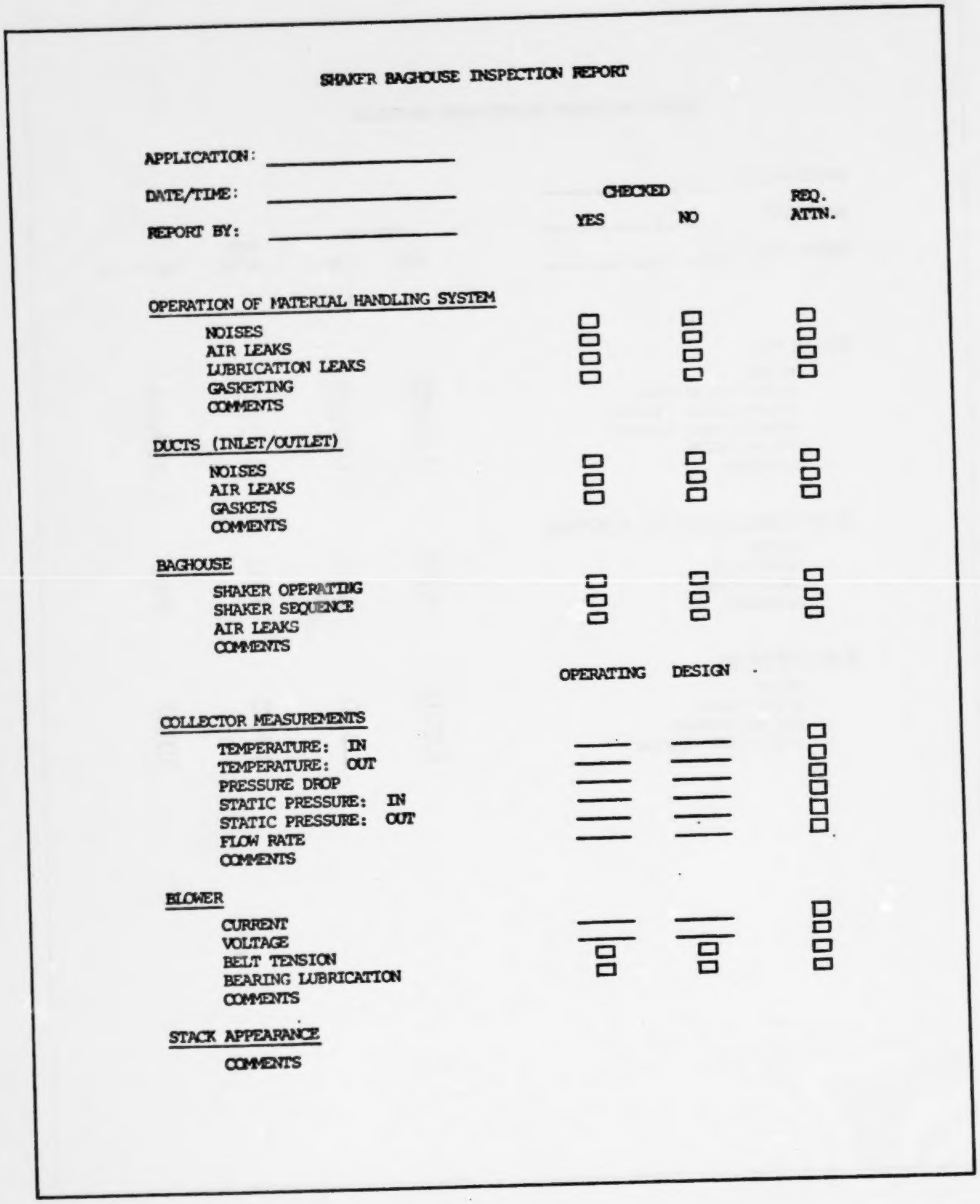
The most important aspect of shutting down a baghouse is the prevention of condensation. A general procedure includes the following steps:

When the process is shut down, it is advisable to continue to operate the baghouse for one complete cycle (including cleaning). This operation purges it with clean air to avoid condensation and ensure that bag contaminants are removed. (In applications where a filter cake is needed upon startup, cleaning is not recommended.)

Shut down the fan.

If possible, isolate the baghouse by closing dampers.

Continue to operate dust removal system until hoppers are clear and then shut off the system.



SHAKFR BAGHOUSE INSPECTION REPORT

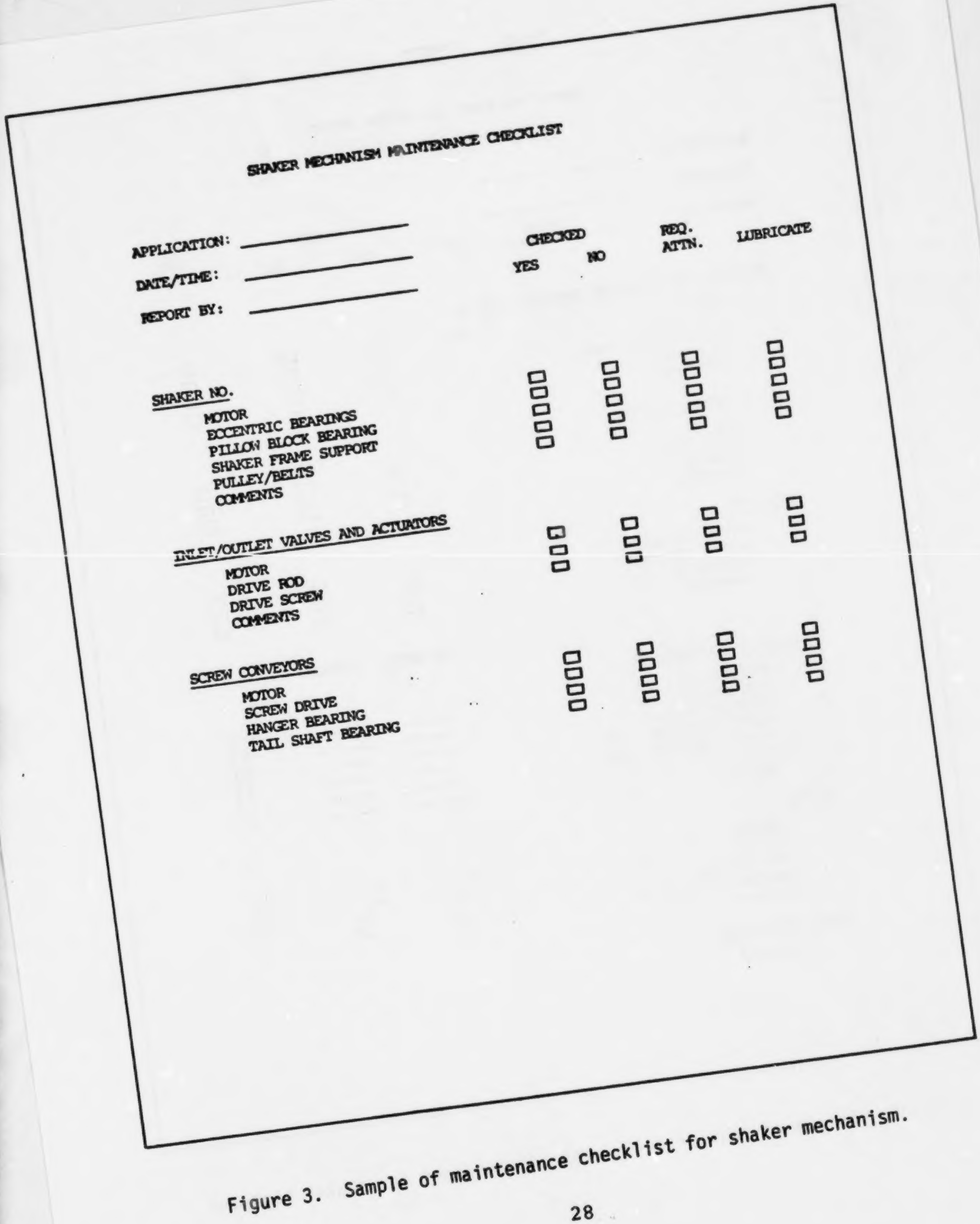
APPLICATION: ____________________

DATE/TIME: ____________________

REPORT BY: ____________________

	CHECKED		REQ. ATTN.
	YES	NO	
OPERATION OF MATERIAL HANDLING SYSTEM			
NOISES	☐	☐	☐
AIR LEAKS	☐	☐	☐
LUBRICATION LEAKS	☐	☐	☐
GASKETING	☐	☐	☐
COMMENTS			
DUCTS (INLET/OUTLET)			
NOISES	☐	☐	☐
AIR LEAKS	☐	☐	☐
GASKETS	☐	☐	☐
COMMENTS			
BAGHOUSE			
SHAKER OPERATING	☐	☐	☐
SHAKER SEQUENCE	☐	☐	☐
AIR LEAKS	☐	☐	☐
COMMENTS			
	OPERATING	DESIGN	
COLLECTOR MEASUREMENTS			
TEMPERATURE: IN	______	______	☐
TEMPERATURE: OUT	______	______	☐
PRESSURE DROP	______	______	☐
STATIC PRESSURE: IN	______	______	☐
STATIC PRESSURE: OUT	______	______	☐
FLOW RATE	______	______	☐
COMMENTS			
BLOWER			
CURRENT	______	______	☐
VOLTAGE	______	______	☐
BELT TENSION	☐	☐	☐
BEARING LUBRICATION	☐	☐	☐
COMMENTS			
STACK APPEARANCE			
COMMENTS			

Figure 2. Sample of routine daily inspection report for shaker baghouse.



SHAKER MECHANISM MAINTENANCE CHECKLIST

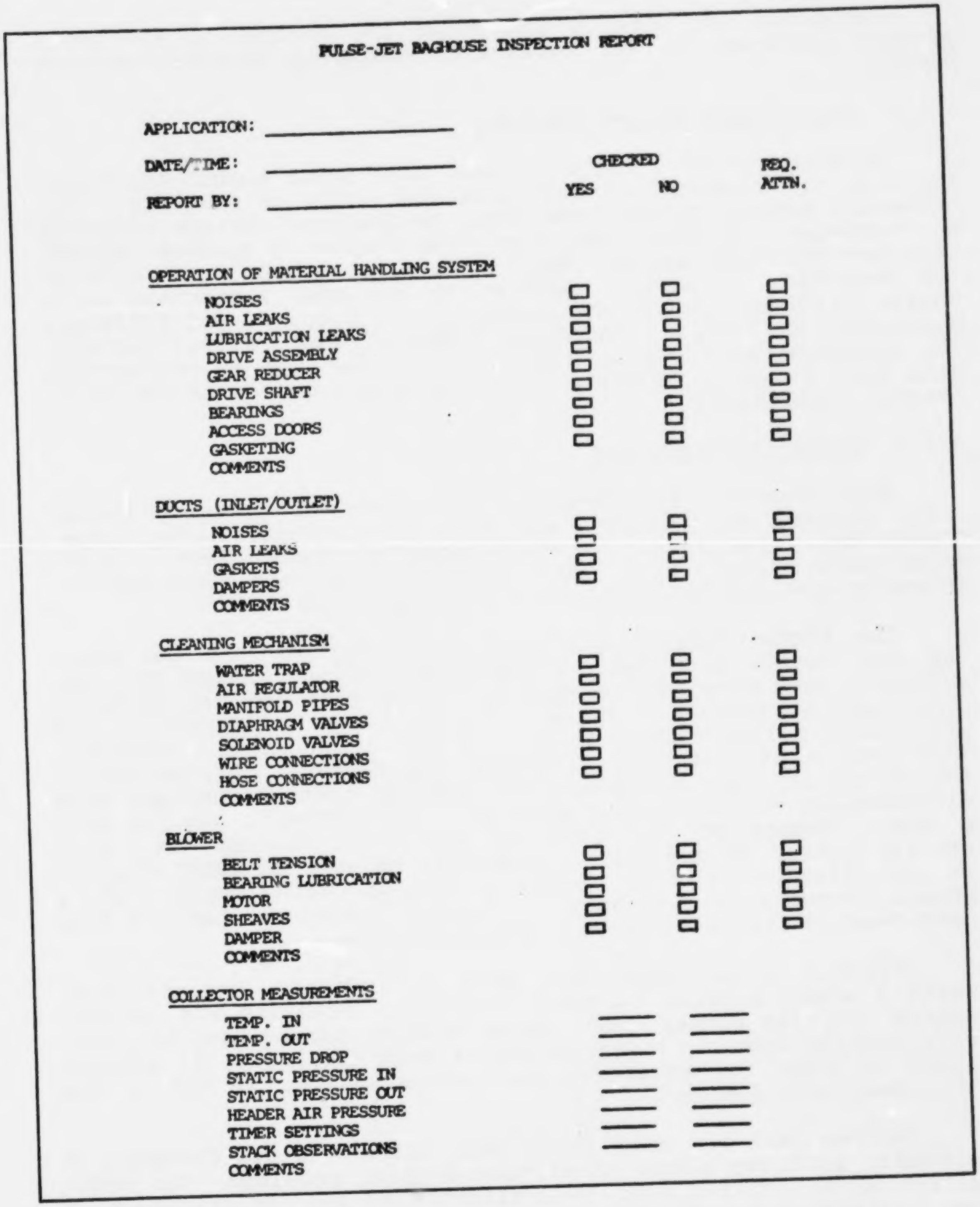
APPLICATION: ______________

DATE/TIME: ______________

REPORT BY: ______________

	CHECKED YES	CHECKED NO	REQ. ATTN.	LUBRICATE
SHAKER NO.				
MOTOR	☐	☐	☐	☐
ECCENTRIC BEARINGS	☐	☐	☐	☐
PILLOW BLOCK BEARING	☐	☐	☐	☐
SHAKER FRAME SUPPORT	☐	☐	☐	☐
PULLEY/BELTS	☐	☐	☐	☐
COMMENTS				
INLET/OUTLET VALVES AND ACTUATORS				
MOTOR	☐	☐	☐	☐
DRIVE ROD	☐	☐	☐	☐
DRIVE SCREW	☐	☐	☐	☐
COMMENTS				
SCREW CONVEYORS				
MOTOR	☐	☐	☐	☐
SCREW DRIVE	☐	☐	☐	☐
HANGER BEARING	☐	☐	☐	☐
TAIL SHAFT BEARING	☐	☐	☐	☐

Figure 3. Sample of maintenance checklist for shaker mechanism.



PULSE-JET BAGHOUSE INSPECTION REPORT

APPLICATION: ____________

DATE/TIME: ____________

REPORT BY: ____________

	CHECKED		REQ. ATTN.
	YES	NO	
OPERATION OF MATERIAL HANDLING SYSTEM			
NOISES	☐	☐	☐
AIR LEAKS	☐	☐	☐
LUBRICATION LEAKS	☐	☐	☐
DRIVE ASSEMBLY	☐	☐	☐
GEAR REDUCER	☐	☐	☐
DRIVE SHAFT	☐	☐	☐
BEARINGS	☐	☐	☐
ACCESS DOORS	☐	☐	☐
GASKETING	☐	☐	☐
COMMENTS			
DUCTS (INLET/OUTLET)			
NOISES	☐	☐	☐
AIR LEAKS	☐	☐	☐
GASKETS	☐	☐	☐
DAMPERS	☐	☐	☐
COMMENTS			
CLEANING MECHANISM			
WATER TRAP	☐	☐	☐
AIR REGULATOR	☐	☐	☐
MANIFOLD PIPES	☐	☐	☐
DIAPHRAGM VALVES	☐	☐	☐
SOLENOID VALVES	☐	☐	☐
WIRE CONNECTIONS	☐	☐	☐
HOSE CONNECTIONS	☐	☐	☐
COMMENTS			
BLOWER			
BELT TENSION	☐	☐	☐
BEARING LUBRICATION	☐	☐	☐
MOTOR	☐	☐	☐
SHEAVES	☐	☐	☐
DAMPER	☐	☐	☐
COMMENTS			
COLLECTOR MEASUREMENTS			
TEMP. IN	______	______	
TEMP. OUT	______	______	
PRESSURE DROP	______	______	
STATIC PRESSURE IN	______	______	
STATIC PRESSURE OUT	______	______	
HEADER AIR PRESSURE	______	______	
TIMER SETTINGS	______	______	
STACK OBSERVATIONS	______	______	
COMMENTS			

Figure 4. Sample of routine daily inspection report for pulse-jet baghouse.

Baghouses are usually shut down for routine or emergency process shutdown, or for routine or emergency baghouse maintenance.

3.3.5 Maintenance During Shutdown

Maintenance of a baghouse must also occur within the housing when the baghouse is shut down and entry is possible. All necessary safety precautions must be followed before entering the baghouse. At this time, the items requiring greatest attention are the bags and any moving mechanism on the dirty side of the baghouse. Figure 5 details an internal inspection of a shaker baghouse. Other checklists can be prepared for different baghouses, components, and other types of dust removal systems. The checklist provided in Figure 5 could be used in conjunction with that shown in Figure 2 as an excellent mechanism for maintenance recordkeeping.

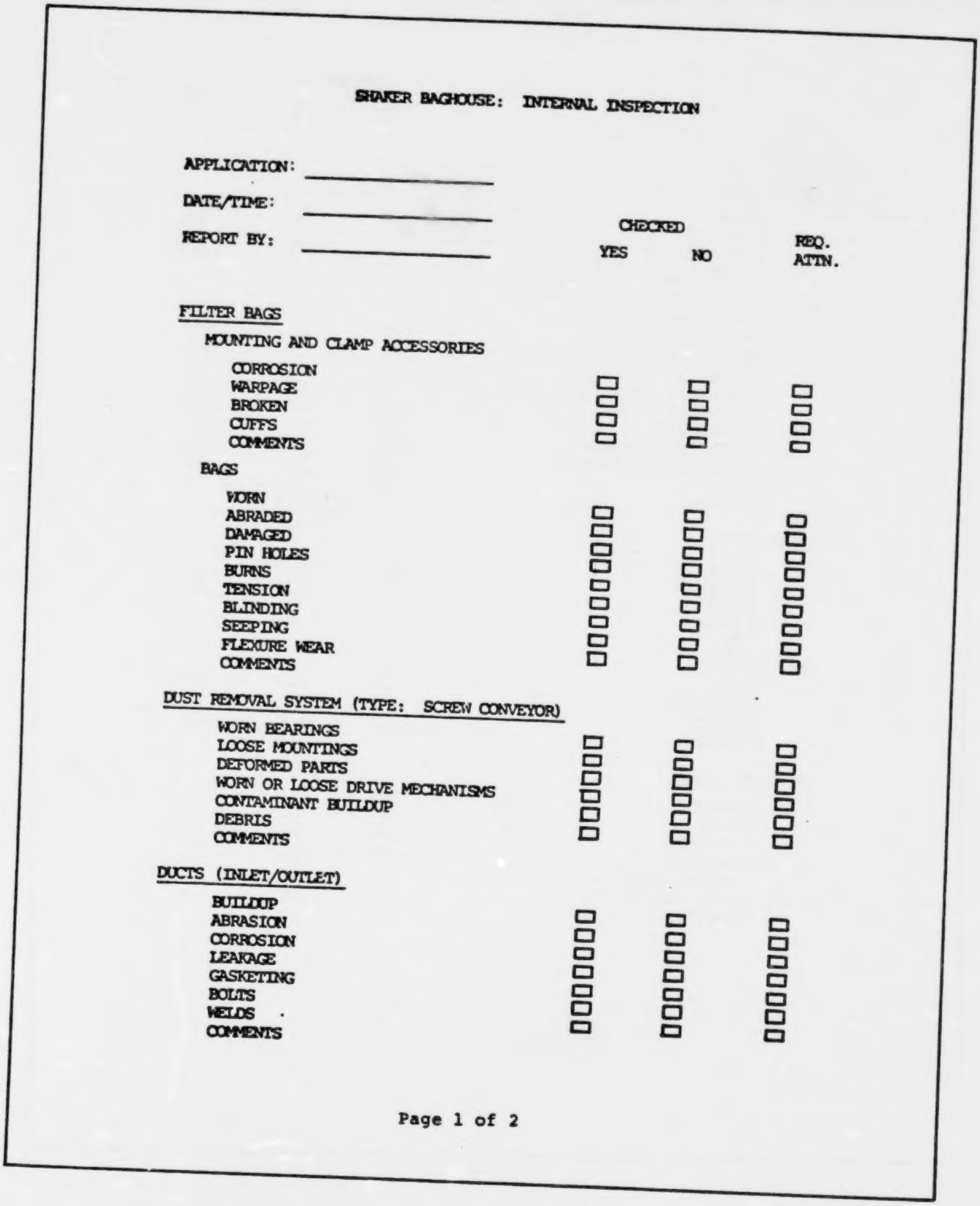
3.3.6 Common Malfunctions

Most baghouse maintenance, regardless of cleaning mechanism, focuses on the bags and moving mechanical parts, especially those parts on the dirty side of the filters. High-maintenance items also vary according to the application. Commonly observed malfunctions are discussed below.

The highest-maintenance item of a baghouse is the bags. The most common problems are tears or pinholes, blinding (cake buildup), and bleeding (seepage). These problems can be diagnosed and subsequently minimized with frequent inspection and preventive maintenance. It should not be construed, however, that such a program will eliminate bag failure. Variations in fabric quality, sewing techniques, quality control, and gas flow distribution within the baghouse also contribute to bag failure. A small number of bag failures may occur during the first several months of operation, generally because of manufacturing or installation defects. Under normal operating conditions, a sudden increase in frequency of failure indicates that the bags have reached the end of their operating life.

Visible stack emissions usually indicate bag failure. Where a stack monitor is used, increased readings are further indicators. In either case, three methods can be used to identify leaking bags: 1) inspection of bags for holes, 2) examination of bags for excessive dust accumulation, 3) use of bag leak detection device.

Valves that are used to isloate individual bag chambers in a shaker baghouse often experience sealing problems. An indication of a poor bag seal is a slight flow and presurization in the isolated compartment. This condition can be determined by viewing the shaking process and observing that the bags are inflated.



SHAKER BAGHOUSE: INTERNAL INSPECTION

APPLICATION: ____________

DATE/TIME: ____________

REPORT BY: ____________

	CHECKED		
	YES	NO	REQ. ATTN.
FILTER BAGS			
MOUNTING AND CLAMP ACCESSORIES			
CORROSION	☐	☐	☐
WARPAGE	☐	☐	☐
BROKEN	☐	☐	☐
CUFFS	☐	☐	☐
COMMENTS			
BAGS			
WORN	☐	☐	☐
ABRADED	☐	☐	☐
DAMAGED	☐	☐	☐
PIN HOLES	☐	☐	☐
BURNS	☐	☐	☐
TENSION	☐	☐	☐
BLINDING	☐	☐	☐
SEEPING	☐	☐	☐
FLEXURE WEAR	☐	☐	☐
COMMENTS			
DUST REMOVAL SYSTEM (TYPE: SCREW CONVEYOR)			
WORN BEARINGS	☐	☐	☐
LOOSE MOUNTINGS	☐	☐	☐
DEFORMED PARTS	☐	☐	☐
WORN OR LOOSE DRIVE MECHANISMS	☐	☐	☐
CONTAMINANT BUILDUP	☐	☐	☐
DEBRIS	☐	☐	☐
COMMENTS			
DUCTS (INLET/OUTLET)			
BUILDUP	☐	☐	☐
ABRASION	☐	☐	☐
CORROSION	☐	☐	☐
LEAKAGE	☐	☐	☐
GASKETING	☐	☐	☐
BOLTS	☐	☐	☐
WELDS	☐	☐	☐
COMMENTS			

Page 1 of 2

Figure 5. Sample of internal inspection report for a shaker baghouse.

	CHECKED		REQ. ATTN.
	YES	NO	
VALVES/DAMPERS			
BUILDUP	☐	☐	☐
CORROSION	☐	☐	☐
CLEARANCE	☐	☐	☐
COMMENTS			
CLEANING MECHANISM (SHAKER)			
SHAKER FRAME	☐	☐	☐
SHAKER HANGER	☐	☐	☐
LINKAGE	☐	☐	☐
CONNECTING ROD ASSEMBLY	☐	☐	☐
CRANKSHAFT	☐	☐	☐
DRIVE MOTOR	☐	☐	☐
PILLOW BLOCK BEARING	☐	☐	☐
SHAKER DRIVE SUPPORT	☐	☐	☐
BELTS	☐	☐	☐
COMMENTS			
TUBE SHEET			
WARPAGE	☐	☐	☐
CORROSION	☐	☐	☐
BUILDUP	☐	☐	☐
COMMENTS			
ACCESS DOORS			
SEALS	☐	☐	☐
GASKETING	☐	☐	☐
LEAKAGE	☐	☐	☐
COMMENTS			
BAGHOUSE HOUSING			
WARPAGE	☐	☐	☐
CRACKS	☐	☐	☐
CORROSION	☐	☐	☐
GASKETING	☐	☐	☐
NUTS AND BOLTS	☐	☐	☐
LINING CRACKED	☐	☐	☐
COMMENTS			

Page 2 of 2

Figure 5 (continued)

If the push rod from poppet valves is subjected to dust, it can affect air cylinder operation. The push rod should be mounted in the vertical position, because horizontal mounting may cause warpage and malfunction.

3.3.7 Troubleshooting Procedures

Recommendations for troubleshooting a shaker and a pulse-jet baghouse are provided below.

Recommendations for Troubleshooting a Shaker Baghouse--

1. Check wear pattern before removing old bags. These patterns may indicate a diffuser problem if abrasion is causing bag failure. If chemical attack is the problem, the pattern may indicate where the moisture originates.
2. Account for shrinkage rate of new bags when adjusting bag tension.
3. Be sure that the entire clamp (bag and screw) is of a noncorrosive material (preferably stainless steel).
4. Use stainless steel, hex-head screws on the bands so that ratchet wrenches or air guns can be used. Air wrenches with pressure regulators can be calibrated with a torque wrench to ensure proper band tightening.
5. Keep bag seams straight and do not torsionally twist the bags.
6. Visually recheck bag tension after the first 8 or 10 hours, sooner if the shaker motor overloads or if the belts break or squeal.
7. Check availability of other bag materials, especially if sufficient leadtime is available. This may bring significant savings and better performance. Current trend is to purchase polyester or glass material for most applications. Other materials, such as polypropylene or nylon, should be considered because they may perform better and be less expensive.
8. Place tight-fitting washer on shaker pins if present holes approach the size of the retaining clip on the pin (shaker) mechanism.

Recommendations for Troubleshooting a Pulse-Jet Baghouse--

1. Stiffen tube sheet if it flexes in order to minimize bag-to-bag abrasion.
2. Align bags to prevent them from touching each other.
3. Check the coefficient of thermal expansion and the rate of fabric shrinkage so that the bags do not deform retainer. If bags are too small for the retainer, they will tear.
4. Align jet in center of bags and make sure it is perpendicular to the tube sheet.
5. Use venturi nozzle, if possible. Although it has a higher initial cost, savings in energy and better cleaning compensate; it also minimizes the shear effect on the upper portion of the bags caused by the cleaning jet pulse. Avoid bag lengths greater than 8 ft., especially if the diameter is not over 4 in. Long bags cause a problem of overcleaning at the top and lack of cleaning at the bottom.
6. Change the diaphragm in the right angle valves as part of routine maintenance. Replace pilot valves if they have a history of failing or sticking.
7. If undercleaning is a problem, minimize the number of transitions in the blow tube piping. Ream out the blow tube orifices to prevent burrs caused by cutting from restricting the flow.
8. Use headers having at least a 6-in. diameter, with the last valve being at least one diameter from the end of the headers.
9. Lubricate or replace all seals and worn bearings as necessary in all rotating equipment.
10. Install a water trap on the compressed air line upstream of the solenoid valve.
11. Check housing for stress cracks caused by pulsing.
12. Weld or braise any loose wires on the retainers. Replace badly bent retainers.

13. Replace all gaskets or other parts when appropriate.

14. Follow the unit through a full cycle to ensure that all valves are operating in a proper sequence.

15. Observe that the seal on the hopper discharge is preventing reentrainment from fan suction or pressure of air conveying system. Use double airlocks, if necessary. Leakage in this component has the effect of creating a higher grain loading, especially with submicrometer particles. Air leakage could be observed by "whistling" air rushing into the system or dust patterns forming at infiltration locations.

16. Do not use a woven material in a pulse-jet collector; use only felted material.

17. If tube sheet leakage is a problem, apply sealer between the bag retainer and the top of the tube sheet. When intermittent puffing occurs, it is usually caused by overcleaning. If all are not puffing, check the row by sychronizing a stop watch with the cleaning timer. If possible, check dump rate of the conveying system.

18. Ensure that hopper operates fast enough to prevent it from becoming more than two-thirds full.

General Troubleshooting Guide--

An extensive list of procedures for troubleshooting and correcting baghouse malfunctions is given in Table 1. This table should be consulted when troubleshooting and diagnosing operational problems (i.e., when a symptom arises from various causes during equipment operation). In the absence of symptoms or malfunction, internal inspection may reveal such problems as bag tears or pinholes, and the subsequent development or malfunction is speculative. For instance, bag tears may result in low pressure drop, high opacity, high air-to-cloth ratio, or other problems.

3.3.8 Spare Parts

The manufacturer of the equipment usually provides a recommended spare parts list. The most important item to stock is bags, preferably a full replacement set. Although there is a bag life expectancy and delivery time, emergencies could arise. Caution should be exercised when inexpensive bags are quoted by a bag fabricator. Poor quality control is usually the reason for cost cutting. A list of replacement parts is provided in Table 2.

TABLE 1. BAGHOUSE TROUBLESHOOTING GUIDE

The following chart lists the most common problems found in a baghouse air pollution control system and offers general solutions. In some instances, the solution is to consult the manufacturer. This may not be necessary in plants that have sufficient engineering know-how available.

Where the information applies to a specific type of baghouse, the following code is used:

RP	Reverse pulse
PP	Plenum pulse
S	Shaker
RF	Reverse flow

Symptom	Cause	Remedy
High baghouse pressure drop	Baghouse undersized	Consult manufacturer Install double bags Add more compartments or modules
	Bag cleaning mechanism not adjusted properly	Increase cleaning frequency Clean for longer duration Clean more vigorously (must check with manufacturer before implementing)
	Compressed air pressure too low (RP, PP)	Increase pressure Decrease duration and/or frequency Check dryer and clean if necessary Check for obstruction in piping
	Repressuring pressure too low (RF)	Speed up repressuring fan Check for leaks Check damper valve seals
	Shaking not vigorous	Increase shaker speed (check with manufacturer)

(continued)

Table 1 (continued)

Symptom	Cause	Remedy
	Isolation damper valves not closing (S, RF, PP)	Check linkage Check seals Check air supply of pneumatic operators
	Isolation damper valves not opening (S, RF, PP)	Check linkage Check air supply on pneumatic operators
	Bag tension too loose (S)	Tighten bags
	Pulsing valves failed (RP)	Check diaphragm valves Check solenoid valves
	Air volume greater than design	Damper system to design point Install fan amperage controls
	Cleaning timer failure	Check to see if timer is indexing to all contacts Check output on all terminals
	Not capable of removing dust from bags	Condensation on bags (see below) Send sample of dust to manufacturer Send bag to lab for analysis for blinding Dryclean or replace bags Reduce air flow
	Excessive reentrainment of dust	Continously empty hopper Clean rows of bags randomly, instead of sequentially (PP, RP)
	Incorrect pressure reading	Clean out pressure taps Check hoses for leaks Check for proper fluid in manometer Check diaphragm in gauge
Low fan motor amperage/ low air volume	High baghouse pressure	See above

(continued)

Table 1 (continued)

Symptom	Cause	Remedy
	Fan and motor sheaves reversed	Check drawings and reverse sheaves
	Ducts plugged with dust	Clean out ducts and check duct velocities
	Fan damper closed	Open damper and lock in position
	System static pressure too high	Measure static on both sides and compare with design pressure Duct velocity too high Duct design not proper
	Fan not operating per design	Check fan inlet configuration and be sure even airflow exists
	Belts slipping	Check tension and adjust
Dust escaping at source	Low air volume	See above
	Ducts leaking	Patch leaks so air does not bypass source
	Improper duct flow balancing	Adjust blast gates in branch ducts
	Improper hood design	Close open areas around dust source Check for cross drafts that overcome suction Check for dust being thrown away from hood by belt, etc.
Dirty discharge at stack	Bags leaking	Replace bags Tie off bags and replace at a later date Isolate leaking compartment if allowable without upsetting system
	Bag clamps not sealing	Check and tighten clamps Smooth out cloth under clamp and reclamp

(continued)

Table 1 (continued)

Symptom	Cause	Remedy
	Failure of seals in joints at clean/dirty air connection	Caulk and tighten clamps Smooth out cloth under clamp and reclamp
	Insufficient filter cake	Allow more dust to build up on bags by cleaning less frequently Use a precoating of dust on bags (S, RF)
	Bags too porous	Send bag in for permeability test and review with manufacturer
Excessive fan wear	Fan handling too much dust	See above
	Improper fan	check with fan manufacturer to see if fan is correct for application
	Fan speed too high	Check with manufacturer
Excessive fan vibration	Buildup of dust on blades	Clean off and check to see if fan is handling too much dust (see above) Do not allow any water in fan (check drain, look for condensation, etc.)
	Wrong fan wheel for application	Check with manufacturer
	Sheaves not balanced	Have sheaves dynamically balanced
	Bearings worn	Replace bearings
High compressed air consumption (RP, PP)	Cleaning cycle too frequent	Reduce cleaning cycle if possible
	Pulse too long	Reduce duration (after initial shock all other compressed air is wasted)
	Pressure too high	Reduce supply pressure if possible

(continued)

Table 1 (continued)

Symptom	Cause	Remedy
	Damper valves not sealing (PP)	Check linkage Check seals
	Diaphragm valve failure	Check diaphragms and springs Check solenoid valve
Reduced compressed air pressure (RP, PP)	Compressed air consumption too high	See above
	Restrictions in piping	Check piping
	Dryer plugged	Replace desiccant or bypass dryer if allowed
	Supply line too small	Consult design
	Compressor worn	Replace rings
Premature bag failure: decomposition	Bag material improper for chemical coposition of gas or dust	Analyze gas and dust and check with manufacturer Treat with neutralizer before baghouse
	Operating below acid dew point	Increase gas temperature Bypass and startup
Moisure in baghouse	System not purged after shutdown	Keep fan running for 5 to 10 minutes after process is shut down
	Wall temperature below dew point	Raise gas temperature Insulate unit Lower dew point by keeping moisture out of system
	Cold spots at strucural members	Fully insulate structural members
	Compressed air introducing water (RP, PP)	Check automatic drains Install aftercooler Install dryer
	Repressuring air causing condensation (RF, PP)	Preheat repressuring air Use process gas as source of repressuring air
High screw conveyor wear	Screw conveyor undersized	Measure hourly collection of dust and consult manufacturer

(continued)

Table 1 (continued)

Symptom	Cause	Remedy
	Conveyor speed too high	Slow down speed
High air lock wear	Air lock undersized	Measure hourly collection of dust and consult manufacturer
	Thermal expansion	Consult manufacturer to see if design allowed for thermal expansion
	Speed too high	Slow down
Material bridging in hopper	Moisture in baghouse	See above Add hopper heaters
	Dust being stored in hopper	Remove dust continuously
	Hopper slope insufficient	Rework or replace hoppers
	Conveyor opening too small	Use a wide-flared trough
Frequent screw conveyor/air lock failure	Equipment undersized	Consult manufacturer
	Screw conveyor misaligned	Align conveyor
	Overloading components	Check sizing to see that each component is capable of handling a 100% delivery from the previous component
High pneumatic conveyor wear	Pneumatic blower too fast	Slow down blower
	Piping undersized	Review design and slow blower or increase pipe size
	Elbow radius too short	Replace with long radius elbows
Pneumatic coneyor pipes plugging	Overloading pneumatic conveyor	Review design
	Slug loading of dust	See above

(continued)

Table 1 (continued)

Symptom	Cause	Remedy
	Moisture in dust	See below
Fan motor overloading	Air volume too high	See below
	Motor not sized for cold start	Damper fan at startup Reduce fan speed Provide heat faster Replace motor
Air volume too high	Ducts leaking	Patch leaks
	Insufficient static pressure	Close damper valve Slow down fan
Reduced compressed air consumption (RP, PP)	Pulsing valves not working	Check diaphragms Check springs Check solenoid valves
	Timer failed	Check terminal outputs
High bag failure: wearing out	Baffle plate worn out	Replace baffle plate
	Too much dust	Install primary collector
	Cleaning cycle too frequent	Slow down cleaning
	Inlet air not properly baffled from bags	Consult manufacturer
	Shaking too violent (S)	Slow down shaking mechanism (consult manufacturer)
	Repressuring pressure too high (RF)	Reduce pressure
	Pulsing pressure too high (RP, PP)	Reduce pressure
	Cages have barbs (RP, PP)	Remove and smooth out barbs
High bag failure: burning	Stratification of hot and cold gases	Force turbulence in duct with baffles

(continued)

Table 1 (continued)

Symptom	Cause	Remedy
	Sparks entering baghouse	Install spark arrestor
	Thermocouple failed	Replace and determine cause of failure
	Failure of cooling device	Review design and work with manufacturer

TABLE 2. REPLACEMENT PARTS FOR BAGHOUSE FILTERS

Bags and accessories: clamps, nuts, bolts, hangers

Bag retainers (pulse jet)

Cleaning mechanism

  Shaker: bearings, hangers, crankshaft, connecting rod, motor belts

  Pulse jet: venturis, solenoid and diaphragm valves, tubing

Timing mechanism

Screw conveyor: belts, hanger bearings, coupling bolts.

Air locks: bearing and seals

Pneumatic: see manufacturer's recommendations

Damper valves: solenoids, seals, cylinders

Magnahelic gauges

Gasketing, caulking, lubricants, special tools

Electrical switches, relays, fuses

The user of the equipment should supplement the manufacturer's recommendations with a spare parts inventory reflecting the particular application. Spare parts for baghouses are not costly, but shipping time is often excessive.

SECTION 4

TECHNICAL ASPECTS OF THE DESIGN, OPERATION, AND MAINTENANCE OF ELECTROSTATIC PRECIPITATORS

Electrostatic precipitators are available in single-stage and two-stage units. In single-stage units, particle charging and collection are done simultaneously, and in two-stage units, particle charging is followed by a separate collection stage. Because most industrial ESP's are single-stage, this report will discuss this type only. Two-stage systems are used for low grain loading and low flow and find application in commercial and small industrial situations.

Other classifications of ESP's are designated by the method of removing precipitated dust from the collector surface (rapper: dry; water spray: wet), shape of collecting surface (plate or cylindrical), and direction of gas flow within the unit (horizontal or vertical).

Most industrial ESP's are of the rapper, plate, and horizontal gas flow type. In operation, the ESP allows the dust-laden gas to flow between negatively charged wire electrodes (discharge electrodes) and nearby grounded plate electrodes (collector electrodes). The wire electrodes are charged to a high electrical potential by an unfiltered d.c. power supply mounted outside the precipitator housing. The applied voltage is high enough to produce a visible corona discharge in the gas immediately surrounding the wire electrodes. Electrons set free in the discharge collide with gas molecules, producing gas ions that in turn collide with dust particles and give them a negative charge. In the strong electric field between the wire and plate electrodes, the electrically charged dust particles migrate to the plate where they are deposited, giving up their charge. Eventually, the thick dust layer can be conveniently removed from the plate by periodic rapping. The dislodged dust falls into the hoppers in the bottom of the precipitator housing, from which it is removed for disposal.

As with baghouses, the operation and maintenance of EPS's will be discussed according to functioning components, with emphasis on design deficiencies that may accentuate O&M problems. The components to be examined are the discharge electrodes, collector electrodes, rappers, dust removal system, electric power supply, and ancillary equipment. Safety will also be discussed. General procedures for routine startup, inspection, shutdown, and troubleshooting are provided. Actual case histories for a dry and a wet ESP are presented in Appendix A to give the user a method for troubleshooting performance problems.

4.1 ELECTROSTATIC PRECIPITATOR COMPONENTS AND OPERATIONAL PARAMETERS

4.1.1 Discharge Electrode System

The discharge electrode ionizes the gas and establishes the electric field for particle charging. The electrodes are metallic and are supplied in cylindrical, square, starred, and barbed wires, in stamped or formed strips. The size and shape of the electrodes is governed by the corona current required. Regardless of the number of fields, the ESP usually contains the same type of wires per field. This may not be totally satisfactory, however, since high concentrations of contaminant are present mostly in the first field. Under these conditions, the high concentration of particulates limits space charge and current flow. Electrodes producing higher currents in the first field should thus be used to achieve higher power density and reduce the load on the power supply in the first field. This power supply could be allowed to operate at less than rated voltage, thereby subjecting the other fields to higher concentrations of dust while not affecting overall system performance. Manufacturers typically use one field for up to 90 percent collection efficiency, two fields for up to 97 percent, three fields up to 99 percent, and four fields for greater than 99 percent.

The discharge electrodes commonly used for industrial ESP's are weighted wire. Rigid wire frame electrodes are becoming more and more prevalent.

Weighted Wire--

The most common configuration of discharge electrodes is the weighted wire, which is typical of most U.S. manufacturers. The material is usually 12-gauge (approximately 0.10-in. diameter) steel spring wire. (The choice of materials is usually dictated by the requirements of corrosion resistance.) The wires are suspended from a support frame at the top of the ESP and held taut by cast iron weights at the bottom. The structure supporting the wire varies from one manufacturer to another. The weights are spaced by a guide frame (typically an eye bolt) and are loosely retained in the guides to allow for wire expansion. The guide frame has been a source of problems: if not properly supported, it may resonate and swing in the airstream, thus affecting dimensional clearance to collector electrodes and putting mechanical stress on the support structure. The guide frames are mounted to the hoppers or ESP housing, usually by a ceramic insulator. Dust buildup and moisture condensation on the insulator can provide a source of electrical leakage to ground.

Wires in the first field are often subjected to localized sparking, especially in regions near the ends of the electrodes. The excessive sparking in this region may come during plate rapping from exposure to high concentrations of falling dust. A shroud surrounding the lower portion (and sometimes the upper) of the wire is provided to reduce this effect and protect the wire.

Each of the wire support frames is integrally fastened by a crossmember, which in turn is connected to a vertical hanger by supports to two (or more) electrical insulators mounted on the ESP roof. Maintenance workers have limited accessibility to the wire supports for wire replacement.

Rigid Frame--

Frame-type electrodes have been commonplace in European designs and are now becoming more prevalant in the United States. Unlike the weighted wire system, rigid frame electrodes require a significantly higher degree of quality control, both in fabrication and erection, and are more costly. The rigid wire frames are usually shop-assembled and shipped and installed in one piece. Poor handling of the frames has often resulted in deformation and deflection of the assembly, distorting the dimensional alignment that is critical to proper electrical performance. Better quality control and shipping precautions are now being taken by manufacturers.

Several designs of rigid frame discharge electrodes are available: the rigid discharge frame with integrally mounted rigid electrodes, mast support discharge wires, and self-supporting rigid discharge electrodes. The first of these is the most popular.

The perimeter of the rigid discharge frame and horizontal frame supports is comprised of pipe or 1-in.-square tubing. The discharge wires are frequently star shaped in cross-section and contain extended points or edges. The wire span between adjacent, interior horizontal frames ranges from 6 to 8 feet. The wires are fastened to the frames by several means: inserting a pair of serrated wedges from opposite sides of the frame to wedge the wire securely, threaded studs with washers, tack welded bolts, or welded studs only.

4.1.2 Collector Electrode System

The charged particulate matter is removed from the gas stream by grounded collector electrodes. The particles that have been charged by the discharge electrode are negative; upon deposition on the grounded (positive) collector plates, they become electrically inert and are removed by rapping.

The electrodes are available in many shapes and are designed to maximize the electric field while minimizing dust reentrainment during rapping. Flat plates have the best electrical characteristics and induce the least turbulence to flow, but excessive reentrainment tends to occur during rapping. In practice, all collector electrodes have some sort of baffle arrangement (aerodynamic shape) to minimize gas velocities near the dust surface as well as to provide stiffness to the plate. Opzel, rod curtain, zigzag, V, V-pocket, channel, offset, shielded, and tulip designs are typically used for baffles.

Plate deformation and distortion are frequently observed. They occur during fabrication, shipment, and site storage. Proper quality control methods must be followed during fabrication, and electrodes must be carefully handled during shipment and storage. The plates should be stored on edge, closely spaced with appropriate dunnage, to remove direct weight from the shipping frames. During operation, thermal and chemical stresses can also result in plate deterioration. Excessive sparking can similarly produce localized plate distortion.

The plate support structure must be rugged enough, especially at welded seams, to withstand mechnical impulse, fatigue, and the vibration provided by the rappers. Facility for alignment at erection and realignment after the shakedown operation must also be provided, especially since thermal stresses contribute to misalignment.

4.1.3 Rappers

Rapping systems for both collector and discharge electrodes are of the electromagnetic impulse, electric vibratory, or pneumatic type. Regardless of the type of dust to be removed, successful removal from the plates depends upon the formation of a congruent dust layer that, upon rapping, will fall in sheets or large agglomerates into the hoppers. (Dust layers on the collection plate can approach 1 inch in thickness before rapping occurs.) Although dust deposits on the wires are usually small, accumulated dust may seriously affect the current density, especially since the electrical forces tend to hold the dust more tenaciously to the discharge electrode than to the collection plate.

Each manufacturer prescribes a particular type of rapper, based on the application and the compatibility with the suspension system, the requirements of the rapping interval, and the intensity and length of each cycle. Pneumatic rappers impart more energy than either electromagnetic rappers or electric vibrators and are prescribed for removal of tenacious dusts.

Rapper shafts that penetrate the ESP housing must be electrically and thermally insulated to avoid electrical and air leakage. Thermal expansion shaft couplings must also be provided, in addition to having positive heated air ventilation for the rapper insulators.

As with discharge electrodes, rapping systems have different designs in the United States and Europe. The U.S. design is dominated by pneumatic and electrically operated vibrators or impactors, and the European design includes mechanical rapping systems. In the latter case, the rapper drive mechanism is externally mounted with a shaft that penetrates the ESP shell. The shaft contains a series of hammers designed to hit anvils at the lower end of the collector plate electrodes and the center, or lower end, of the discharge wire frame. The hammers may be staggered, as in single-frame rapping, or in parallel groups wherein a section or group of frames is rapped simultaneously.

4.1.4 Dust Removal Systems

Hoppers are used to collect and store particulates removed from the electrodes. In ESP applications (in contrast to baghouses), center dividing baffles are used to prevent gas from bypassing electrical charging zones. Methods available to remove dusts accumulated in hoppers include containers, dry vacuum, wet vacuum, screw, and drag conveyors. Vibrators, thermal insulation, heating cables, and steam tracing may be used to make the contaminant fluid for easy removal. For convenience in removing buildup and excessive dust accumulation, poke holes should be provided.

The hopper interiors must be free from all physical projections, even ladders, that may provide surfaces for buildup. Access doors to hoppers must be key interlocked. Level alarms should be installed; if center hopper dividing baffles are used, a level indicator is needed for each section. If only one indicator is available, the side that is evacuated would not alarm even if the adjacent one was full.

Two-thirds of the dust collected by the ESP is deposited in the inlet hopper. These hoppers also act as settling chambers, collecting large particulates not exposed to the electrode system, and must therefore be properly sized. The hopper section and conveyor trough of the ESP must also be designed to accommodate thermal expansion.

4.1.5 Electric Power Supply

Electrostatic precipitators operate on high-voltage d.c. power which is supplied with negative potential impressed on the discharge electrodes. The power supply consists of the voltage control system (which varies the unfiltered voltage wave form as applied to the discharge electrode); the step-up transformer (which steps up line voltage to required precipitator potential); and the rectifier (which converts a.c. to d.c., full or half wave). The control system can be operated manually or automatically and should be operated with the largest voltage possible with minimum arcing. The automatic voltage control prevents the arcing potential from varying as the type of gas, composition, humidity, temperature, and dust concentrations change. If excessive arcing is allowed to occur, the effective potential to the ESP is lowered, collector electrode dust is loosened (assists reentrainment), and the discharge electrode wires tend to fatigue, erode, and melt. When arcing does occur, the applied voltage must be rapidly reduced to extinguish the arc. This is the function of the automatic voltage control system.

The number of times per minute that electrical breakdown occurs between the discharge wire and collector electrode is called the spark rate. It depends on the applied voltage for a given set of precipitator conditions. Increasing the spark rate results in a greater percentage of input power being wasted. Typically, a range of 50 to 150 sparks/min is considered normal. Some precipitators operate at the maximum voltage or current settings on the power supply with no sparking. In collection of low-resistant dusts, where the electric field and ash deposit are insufficient to initiate sparking, no sparking condition may arise. A precipitator not sparking does not mean that the unit is underworked.

The behavior of both clean and dirty electrodes is measured by the primary and secondary voltage/current relationships from the transformer/ rectifier (T/R) set. Clean plate data should be acquired after process shutdown and after completion of sufficient rapping to remove plate and wire dust accumulations. This information provides a basis for comparison with subsequent operational performance and is especially useful for identifying electrical problems and equipment deterioration.

Dirty plate data should be acquired during process operation and when rappers are off.

Ideally the control panel should contain display meters to monitor primary and secondary voltage and secondary current and spark rate. Although highly recommended, a secondary voltage meter is often not installed on the transformer. This situation can be alleviated by the temporary installation of a voltage divider network. The control cabinet contains all required devices and instruments needed to monitor (display meters) and control the operation of the ESP. Positive air ventilation, provided by a filtered intake air fan, helps to protect the internal components of the control cabinet.

The T/R set, which is mounted on the ESP roof, is usually hermetically sealed. These components are submerged in a tank filled with dielectric fluid used for cooling. The tank is equipped with high-voltage bushings, liquid level gauge, drain valve, ground plug, filling plug, lifting lugs, and surge arrestors (which discharge any harmful transients appearing across the d.c. metering circuit to ground).

An electrical conductor in the form of a pipe transmits the voltage output to the support insulator bushing, which is connected to the high-tension support frame from which the discharge wires are suspended. The insulators are housed in a casing or compartment that must be kept clean and dry to prevent ESP dust and moisture from accumulating. Warm, filtered, pressured air is thus supplied to avoid these problems. The pressure of the air delivered to the insulator housings must be sufficiently positive to override the pressure in the ESP casing.

4.1.6 Gas Distribution

The overall performance of the ESP, like that of the baghouse, depends on the uniformity of the gas distribution within the casing. Adequate distribution of flow is provided by installing baffle plates or screens in the inlet transition to the ESP. Laboratory model studies of flow distribution are often performed to assist in the design of the baffles and the casing.

The ESP provides an inlet transition that slows flow velocity to values that are difficult to measure by standard pitot tube methods, thus requiring hot-wire anemometry. Nonuniform flow can seriously affect performance. If it is suspected, the system may need to be deenergized, so that flow distribution can be measured. Nonuniform flow may be identified during a period set aside in the construction schedule to allow these measurements to be taken before startup.

4.1.7 Safety

The ESP and its associated components require an unusual set of safety precautions compared with other types of air pollution control equipment. The high voltage impressed on the system exposes workers to the danger of electrocution. For this reason, safety procedures must be developed.

Safety Key Interlock System--

A mechanical safety interlock system must be designed for all access doors and must be retrofitted on older ESP's. The system should be an integrally coupled series of keys that performs the following sequence of controls: when the system is activated, the power supply is deenergized, the power supply load for the ESP is grounded by a high-voltage switch; and all power supplies on a given segment or subdivision of the ESP are appropriately grounded. Interlock keys are obtained to gain access to that particular subdivision only. Good design practice includes the rapping and conveyor components within the interlock system.

Grounding Hooks--

Every ESP should be equipped with grounding hooks or chains at usual maintenance access points. The hooks are to be applied to components within the reach of a worker from the access door. This precaution ensures that the high-voltage system is grounded and that any residual or extraneous electric charge is removed.

Grounding Network--

The grounding conductor should be sized according to the national electric code and scaled according to the capacity of the maximum feeder cable feeding the power supply. If the power supply contains isolable subassemblies, it will have short circuit capability. The grounding conductor must, therefore, be continuous, starting at the feeder and forming a network combining all points of the power supply (control cabinets, regulating components, T/R set). The ground should also extend to the ESP structures (hopper junctions).

During sparking and arcing, high currents flow in the form of pulses. These currents flow on the surface of conductors rather than through them, and the ground conductor should thus be adequately sized for the available surface. Jumpers and conductors of the appropriate size are necessary to ensure electrical integrity between key components. For example, a lack of electrical integrity could arise in the components from the power supply to the ESP. The typical procedure is to use a coaxial pipe and a grounded cylindrical duct known as a guard. The guard is composed of individual sections with bolted flanges. At the interface of each flange, a jumper must be provided to allow and maintain continuity of ground.

T/R Sets--

The T/R components are immersed in an oil bath of mineral oil or askarel fireproof oil. If askarel oil is subjected to arcing, hydrogen chloride may be generated, and maintenance personnel should exercise extreme caution when servicing these components. It should be noted that askarel contains polychlorinated biphenyl (PCB); disposal of this oil thus requires special consideration.

Mechanical--

The ESP has moving parts that are usually controlled by timers. A worker could be injured if he enters a component when the drive is operating, or if the drive is started while he is inside the system. Coupling these drives (rappers and conveyors) to the interlock system is therefore recommended. Dust buildup on uncleaned collector electrodes could break loose and liberate large amounts of dust, seriously affecting vision and breathing.

4.1.8 Conclusions

It is poor economy to shut down a plant to repair or service a poorly designed ESP. The following are some of the features of modern design that contribute directly to operational reliability.

> High-voltage support insulators mounted in individual roof-mounted, insulator housings provide several operation advantages:
>
> > Insulators are far removed from gas stream.
> >
> > Insulators can be inspected, cleaned, or replaced from above without entering casing.
> >
> > Insulator compartment ventilation system can be serviced easily.
>
> Discharge and collector electrode field must be suspended from shop-fabricated grids.
>
> Discharge electrode wires must be especially fitted on both ends to ensure good electrical contact, eliminating arcing and extending life.
>
> Casing roof, walls, and hoppers must be of clean exterior design to facilitate application and continuity of thermal insulation.
>
> Pyramidal hoppers must be equipped with flush access doors, poke holes, steep valley angles, and large flanged outlets. Hoppers can be equipped with heating coils, vibrators, hammers, and dust level indicators.
>
> Safety-key-interlocked, quick-opening doors provide easy access through roof and sides of casing into suitably sized access passages above, below, and between every high-voltage discharge electric field.

4.2 ELECTROSTATIC PRECIPITATOR OPERATION AND MAINTENANCE

The previous sections provided background information on the various operational components of the ESP, particularly the design features that will improve performance and reduce maintenance. Proper operation and maintenance of an EPS also requires familiarity with procedures for equipment startup, shutdown, inspection, recognition of common malfunctions, and troubleshooting. These procedures are concisely prepared to simplify the inspection, observations, and interpretations of the various components. Discussion of the cause and effect relationship and the impact on performance is also provided.

4.2.1 Pre-Startup Inspection

The inspection performed before startup is critical to the performance of an ESP. The precipitator may not be operational for one of three reasons:

New installation requiring shakedown and debugging

Process shutdown resulting in ESP shutdown

ESP shutdown for maintenance

Regardless of the reason for shutdown, an opportunity exists while the unit is down to perform a thorough inspection. An example of a checklist for visual and mechanical inspection is provided in Figure 6.

This checklist is a guideline only. A specific list should be tailored for each ESP system. The inspection survey during shutdown should include all ductwork and components from the upstream emissions source to the stack.

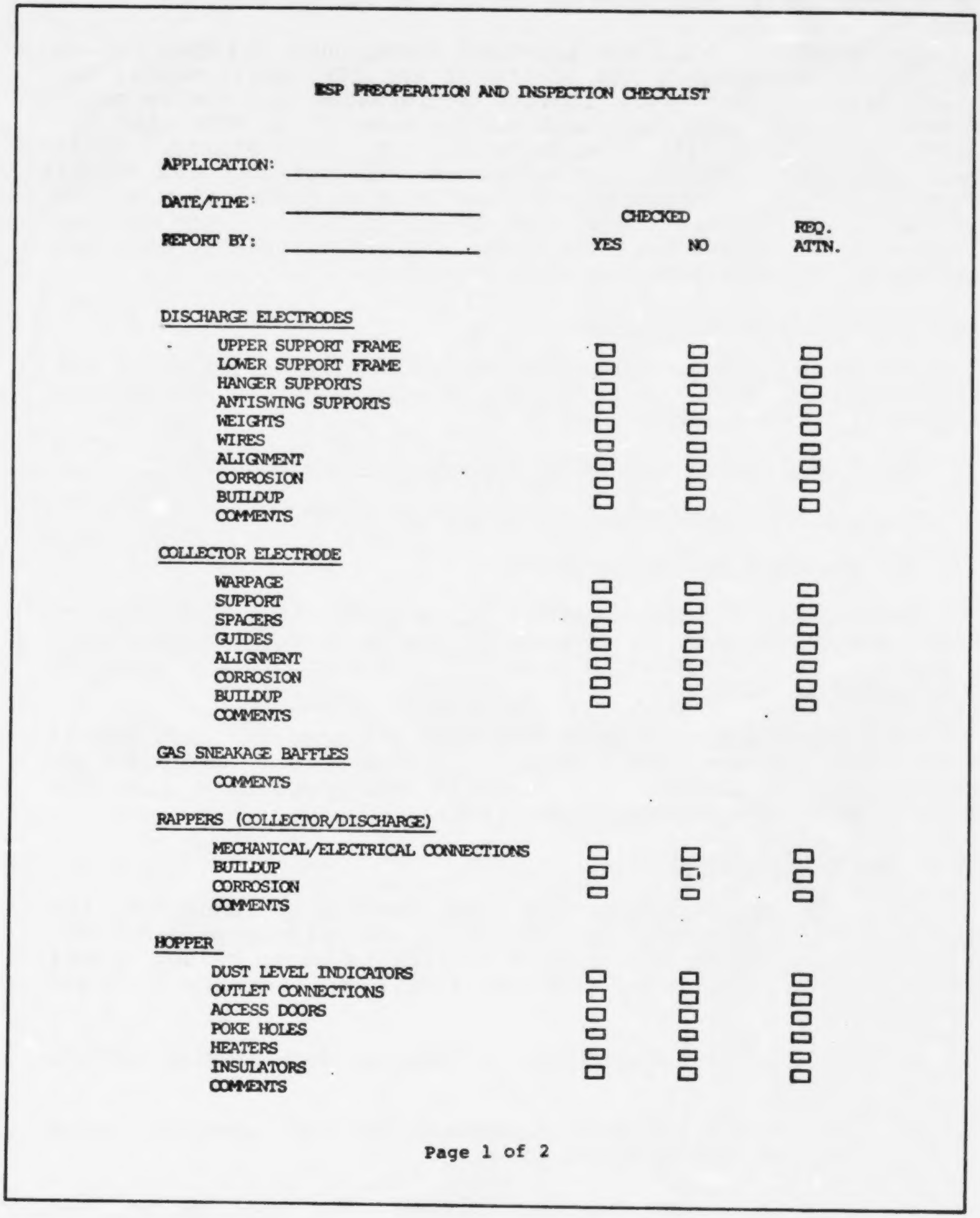
4.2.2 Routine Startup

After the precipitator has been thoroughly inspected, the unit should be buttoned up (following all safety procedures). An outline procedure for routine startup is given below. Power on/off buttons with green and red lights are usually provided for components.

1. Follow key interlock procedures for closing access doors.

2. Preheat insulator compartments for several hours before energizing system.

3. Activate dust handling system (air lock, screw conveyors, etc.).



ESP PREOPERATION AND INSPECTION CHECKLIST

APPLICATION: ____________________

DATE/TIME: ____________________

REPORT BY: ____________________

	CHECKED YES	 NO	REQ. ATTN.
DISCHARGE ELECTRODES			
UPPER SUPPORT FRAME	☐	☐	☐
LOWER SUPPORT FRAME	☐	☐	☐
HANGER SUPPORTS	☐	☐	☐
ANTISWING SUPPORTS	☐	☐	☐
WEIGHTS	☐	☐	☐
WIRES	☐	☐	☐
ALIGNMENT	☐	☐	☐
CORROSION	☐	☐	☐
BUILDUP	☐	☐	☐
COMMENTS			
COLLECTOR ELECTRODE			
WARPAGE	☐	☐	☐
SUPPORT	☐	☐	☐
SPACERS	☐	☐	☐
GUIDES	☐	☐	☐
ALIGNMENT	☐	☐	☐
CORROSION	☐	☐	☐
BUILDUP	☐	☐	☐
COMMENTS			
GAS SNEAKAGE BAFFLES			
COMMENTS			
RAPPERS (COLLECTOR/DISCHARGE)			
MECHANICAL/ELECTRICAL CONNECTIONS	☐	☐	☐
BUILDUP	☐	☐	☐
CORROSION	☐	☐	☐
COMMENTS			
HOPPER			
DUST LEVEL INDICATORS	☐	☐	☐
OUTLET CONNECTIONS	☐	☐	☐
ACCESS DOORS	☐	☐	☐
POKE HOLES	☐	☐	☐
HEATERS	☐	☐	☐
INSULATORS	☐	☐	☐
COMMENTS			

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Figure 6. Preoperation and inspection checklist for electrostatic precipitator.

	CHECKED		
	YES	NO	REQ. ATTN.
SCREW CONVEYOR			
DEBRIS	☐	☐	☐
BUILDUP	☐	☐	☐
CORROSION	☐	☐	☐
MOTOR	☐	☐	☐
SCREW DRIVE	☐	☐	☐
HANGER BEARINGS	☐	☐	☐
TAIL SHAFT BEARING	☐	☐	☐
COMMENTS			
T/R SET			
SURGE ARRESTOR GAP	☐	☐	☐
TRANSFORMER LIQUID LEVEL	☐	☐	☐
GROUND CONNECTIONS	☐	☐	☐
HIGH TENSION BUS DUCT	☐	☐	☐
CONDUITS	☐	☐	☐
FULL WAVE SWITCH BOX	☐	☐	☐
ALARM CONNECTIONS	☐	☐	☐
GROUND SWITCH OPERATION	☐	☐	☐
HIGH VOLTAGE CONNECTIONS	☐	☐	☐
REGISTER BOARD	☐	☐	☐
COMMENTS			
INSULATOR COMPARTMENT			
FILTER COMPARTMENT	☐	☐	☐
DUCTS/INSULATION	☐	☐	☐
FLOW	☐	☐	☐
TEMPERATURE	☐	☐	☐
MOTOR	☐	☐	☐
PRESSURE	☐	☐	☐
HEATER	☐	☐	☐
COMMENTS			
GAS DISTRIBUTION			
INLET/OUTLET TRANSITION	☐	☐	☐
JOINTS	☐	☐	☐
BUILDUP	☐	☐	☐
CORROSION	☐	☐	☐
COMMENTS			
BAFFLES			
VIBRATORS	☐	☐	☐
JOINTS	☐	☐	☐
WARPAGE	☐	☐	☐
BUILDUP	☐	☐	☐
CORROSION	☐	☐	☐
COMMENTS			
DUCTS (INLET/OUT/STACK)			
LEAKAGE	☐	☐	☐
JOINTS	☐	☐	☐
GASKETING	☐	☐	☐
DAMPERS	☐	☐	☐
COMMENTS			

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Figure 6 (continued)

4. Operate discharge and collector electrode rapping system.

5. Operate gas distribution baffle plate vibrators.

6. Turn on high voltage (manual mode) for one section only and bring up input voltage slowly (10 percent increments) to rated voltage or rated current while recording panel meter readings. This procedure is commonly referred to as an airload test. The test establishes reference readings and checks operation of electrical equipment, clearances, etc. After these readings are recorded, turn down high voltage on the field and similarly perform an airload test on the next field. If excessive sparking or d.c. readings are obtained, another internal inspection may be necessary.

7. If system operates satisfactorily, turn off T/R sets.

8. Open bypass dampers.

9. Start blower

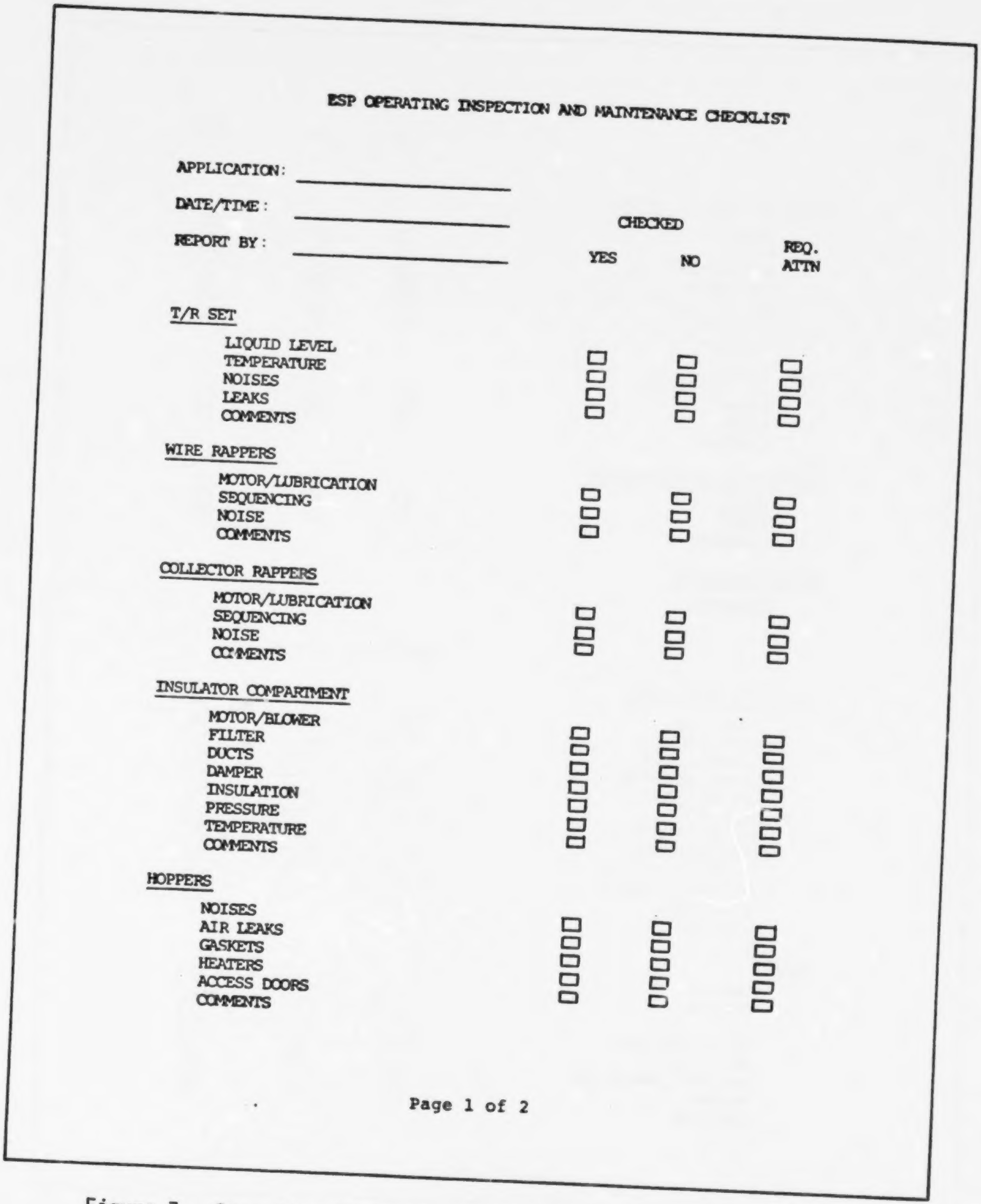
10. If possible, preheat the ESP by pulling hot, clean air through the system, thus avoiding condensation of moisture and contaminant gases. Buildup of condensed material on electrodes is difficult to remove: energize one field only to minimize the effect.

11. Allow contaminant gases to pass through the unit.

12. Record data from monitoring instrumentation (fan motor amperage and voltage; temperatures; a.c. voltage/current; d.c. voltage/current; spark rate).

4.2.3 Routine Inspection and Maintenance During Operation

During routine operation, an inspection procedure that includes a recording of ESP operation data should be used. A sample of a routine daily inspection checklist for an ESP is provided in Figure 7. Only visual inspection of the unit is possible, and therefore only instrumented operational parameters can be obtained. The checklist gives direction and guidance to a maintenance worker for items to observe and check. A tailor-made checklist should be prepared by the user and vendor that is based on the specific components and monitors.



ESP OPERATING INSPECTION AND MAINTENANCE CHECKLIST

APPLICATION: ____________________

DATE/TIME: ____________________

REPORT BY: ____________________

	CHECKED		
	YES	NO	REQ. ATTN
T/R SET			
LIQUID LEVEL	☐	☐	☐
TEMPERATURE	☐	☐	☐
NOISES	☐	☐	☐
LEAKS	☐	☐	☐
COMMENTS			
WIRE RAPPERS			
MOTOR/LUBRICATION	☐	☐	☐
SEQUENCING	☐	☐	☐
NOISE	☐	☐	☐
COMMENTS			
COLLECTOR RAPPERS			
MOTOR/LUBRICATION	☐	☐	☐
SEQUENCING	☐	☐	☐
NOISE	☐	☐	☐
COMMENTS			
INSULATOR COMPARTMENT			
MOTOR/BLOWER	☐	☐	☐
FILTER	☐	☐	☐
DUCTS	☐	☐	☐
DAMPER	☐	☐	☐
INSULATION	☐	☐	☐
PRESSURE	☐	☐	☐
TEMPERATURE	☐	☐	☐
COMMENTS			
HOPPERS			
NOISES	☐	☐	☐
AIR LEAKS	☐	☐	☐
GASKETS	☐	☐	☐
HEATERS	☐	☐	☐
ACCESS DOORS	☐	☐	☐
COMMENTS			

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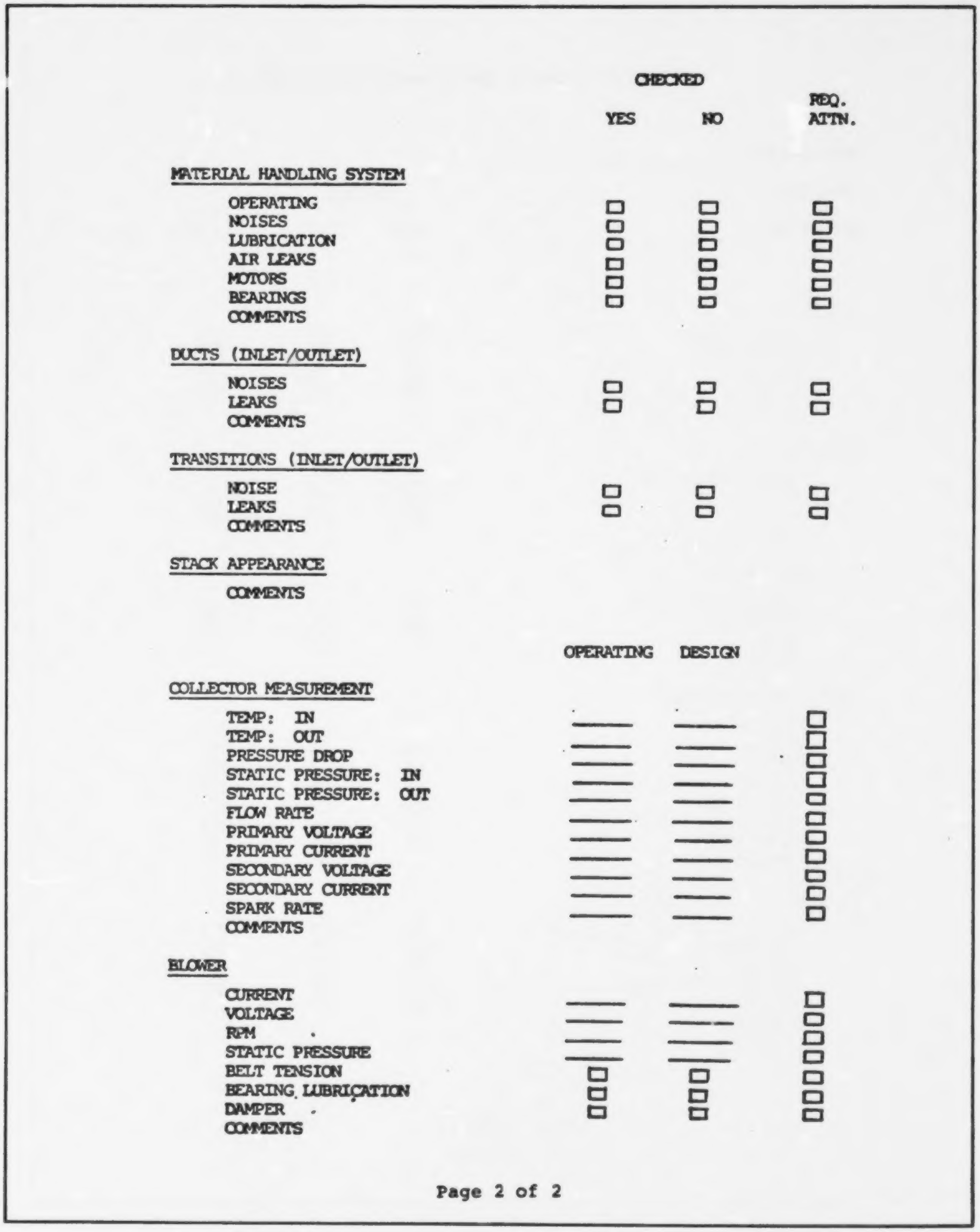
Figure 7. Operating inspection and maintenance checklist for an electrostatic precipitator.



	CHECKED		
	YES	NO	REQ. ATTN.
MATERIAL HANDLING SYSTEM			
OPERATING	☐	☐	☐
NOISES	☐	☐	☐
LUBRICATION	☐	☐	☐
AIR LEAKS	☐	☐	☐
MOTORS	☐	☐	☐
BEARINGS	☐	☐	☐
COMMENTS			
DUCTS (INLET/OUTLET)			
NOISES	☐	☐	☐
LEAKS	☐	☐	☐
COMMENTS			
TRANSITIONS (INLET/OUTLET)			
NOISE	☐	☐	☐
LEAKS	☐	☐	☐
COMMENTS			
STACK APPEARANCE			
COMMENTS			

	OPERATING	DESIGN	
COLLECTOR MEASUREMENT			
TEMP: IN	______	______	☐
TEMP: OUT	______	______	☐
PRESSURE DROP	______	______	☐
STATIC PRESSURE: IN	______	______	☐
STATIC PRESSURE: OUT	______	______	☐
FLOW RATE	______	______	☐
PRIMARY VOLTAGE	______	______	☐
PRIMARY CURRENT	______	______	☐
SECONDARY VOLTAGE	______	______	☐
SECONDARY CURRENT	______	______	☐
SPARK RATE	______	______	☐
COMMENTS			
BLOWER			
CURRENT	______	______	☐
VOLTAGE	______	______	☐
RPM	______	______	☐
STATIC PRESSURE	______	______	☐
BELT TENSION	☐	☐	☐
BEARING LUBRICATION	☐	☐	☐
DAMPER	☐	☐	☐
COMMENTS			

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Figure 7 (continued)

4.2.4 Routine Shutdown

An ESP is shut down primarily because of routine or emergency process shutdown, routine ESP maintenance, or emergency ESP malfunction. In these situations, the ESP should continue to be operated until it is purged with clean air. The following steps are then taken:

1. Stop blower.
2. If possible, isolate ESP by closing inlet/outlet dampers.
3. Shut down T/R set.
4. Continue to operate rapping and dust removal system until wires and plates are believed to be clean; then shut down rappers and dust removal system (make sure that hoppers are clean).
5. Open access doors following interlock procedure.
   Note: Hopper access doors should be opened with care because hot dust may be packed against them.
6. Use ground hooks to remove extraneous electric charge buildup.
7. Allow system to cool and dust to settle before entering.
8. Allow insulator compartment vent system to operate.

4.2.5 Maintenance During Shutdown

When the ESP can be entered, internal inspection can be commenced. It is advisable to leave the insulator compartment vent heaters on during shutdown to prevent moisture from condensing on the high-voltage insulators. The high-maintenance items, in decreasing order of prevalence, are:

Discharge electrode breakage

Plugged hoppers

Insufficient rapping

Insulator bushing failure

Electrical component breakdown.

The checklists provided in Figures 6 and 7 can be used to provide a methodical program of inspection during shutdown. These checklists will also provide an excellent mechanism for maintenance recordkeeping.

4.2.6 Common Malfunctions

Other than changes in process conditions, the most common malfunction associated with ESP performance is from broken discharge wires and plugged hoppers. A detailed list of the causes and effects of malfunctions, categorized according to functioning component, is given in the following pages. In some cases, solutions to the problems are provided. Table 3 provides a summary of common ESP malfunctions.

Discharge Electrodes-

In a weighted wire design, a broken wire may swing freely and cause shorting between discharge and collector electrodes, usually immobilizing an entire field. Wire breakage results from electrical, mechanical, or chemical problems.

Electrical:

Electric erosion (arcing) is the principal cause of failure.

Minimum clearance between electrodes results in repeated sparkover, causing local heating and vaporization of metal. The tension from the suspension weights causes ultimate failure.

Breakage can occur on shroud as well as wire and usually occurs on the lower portion of wire.

Mechanical:

Excessive rapping breaks wire.

Crimps and bends are sources of fatigue with rapping and vibration.

Poor electrical alignment causes the wire frame to oscillate, fatiguing wires and increasing sparking.

Swinging wire frames can often be detected by listening for the regular snap of the arc-over.

Chemical:

Acid gases corrode wires. Material flakes off during rapping, thus exposing new surfaces to additional corrosion attack.

TABLE 3. SUMMARY OF PROBLEMS ASSOCIATED WITH ELECTROSTATIC PRECIPITATORS

Malfunction	Cause	Effect on ESP efficiency	Corrective action	Preventive measures
Poor electrode alignment	Poor design Ash buildup on frame hoppers Poor gas flow	Can drastically affect performance and lower efficiency	Realign electrodes Correct gas flow	Check hoppers frequently for proper operation
Broken electrodes	Wire not rapped clean, causes an arc which embrittles and burns through the wire. Clinkered wire. Causes: a) poor flow area, distribution through unit is uneven; b) excess free carbon due to excess combustion air or fan capacity insufficient for demand required; c) wires not properly centered; d) ash buildup resulting in bent frame, same as c); e) clinker bridges the plates and wire shorts out; f) ash buildup, pushes bottle weight up causing sag in the wire; g) J hooks have improper clearances to the hanging wire; h) bottle weight hangs up during cooling, causing a buckled wire; i) ash buildup on bottle weight to the frame forms a clinker and burns off the wire.	Reduction in efficiency due to reduced power input, bus section unavailability	Replace electrode	Boiler problems; check space between recording steam and air flow pens, pressure gauges; fouled screen tubes. Inspect hoppers Check electrodes frequently for wear Inspect rappers frequently
Distorted or skewed electrode plates	Ash buildup in hoppers Gas flow irregularities High temperatures	Reduced efficiency	Repair or replace plates Correct gas flow	Check hoppers frequently for proper operation; Check electrode plates during outages
Vibrating or swinging electrodes	Uneven gas flow Broken electrodes	Decreases in efficiency due to reduced power input	Repair electrode	Check electrodes frequently for wear

(continued)

TABLE 3 (continued)

Malfunction	Cause	Effect on ESP efficiency	Corrective action	Preventive measures
Inadequate level of power input (voltage too low)	High dust resistivity Excessive ash on electrodes Unusually fine particle size Inadequate power supply Inadequate sectionalization Improper rectifier and control operation Misalignment of electrodes	Reduction in efficiency	Clean electrodes; gas conditioning or alterations in temperature to reduce resistivity; Increase sectionalization	Check range of voltages frequently to make sure it is correct in situ resistivity measurements
Back corona	Ash accumulated on electrodes causing excessive sparking, requiring reduction in voltage charge	Reduction in efficiency	Same as above	Same as above
Broken or cracked insulator or flower pot bushing leakage	Ash buildup during operation causes leakage to ground Moisture gathered during shutdown or low load operation	Reduction in efficiency	Clean or replace insulators and bushings	Check frequently Clean and dry as needed; Check for adequate pressurization on top housing
Air leaks in through hoppers	From dust conveyor	Lower efficiency; dust reentrained through ESP	Seal leaks	Identify early by increase in ash concentration at bottom of exit to ESP
Air leaks in through ESP shell	Flange expansion	Same as above, also causes intense sparking		
Gas bypass around ESP: -dead passage above plates -around high tension frame	Poor design - improper isolation of active portion of ESP	Only small percentage drop in efficiency unless severe	Baffling to direct gas into active ESP section	Identify early by measurement of gas flow in suspected areas

(continued)

TABLE 3 (continued)

Malfunction	Cause	Effect on ESP efficiency	Corrective action	Preventive measures
Corrosion	Temperature goes below dewpoint	Negligible until precipitation interior plugs or plates are eaten away; air leaks may develop, causing significant drops in performance	Maintain flue gas temperature above dewpoint	Energize precipitator after boiler system has been on line for ample period to raise flue gas temperature above acid dewpoint
Hopper pluggage	Wires, plates, insulators fouled becaused of low temperature Inadequate hopper insulation Improper maintenance Boiler leaks causing excess moisture Ash conveying system malfunction: gasket leakage, blow malfunction, or solenoid valves Misadjustment of hopper vibrators Material dropped into hopper from bottle weights Solenoid, timer malfunction Suction blower filter not changed	Reduction in efficiency	Provide proper flow of ash	Frequent checks for adequate operation of hoppers Provide heater thermal insulation to avoid moisture condensation
Inadequate rapping, vibrators fail	Ash buildup Poor design Rappers misadjusted	Resulting buildup on electrodes may reduce efficiency	Adjust rappers with optical dust measureing instrument in ESP exit stream	Frequent checks for adequate operation of rappers
Too intense rapping	Poor design Rappers misadjusted Improper rapping force	Reentrains ash, reduces efficiency	Same as above	Same as above Reduce vibrating or impact force

(continued)

TABLE 3 (continued)

Malfunction	Cause	Effect on ESP efficiency	Corrective action	Preventive measures
Control failures	Power failure in primary system Transformer or rectifier failure: a) insulation breakdown in transformer b) arcing in transformer between high voltage switch contacts c) leaks or shorts in high voltage structure d) insulating field contamination	Reduced efficiency	Find source of failure and repair or replace	Pay close attention to daily readings of control room instrumentation to spot deviations from normal readings
Sparking	Inspection door ajar Boiler leaks Plugging of hoppers Dirty insulators	Reduced efficiency	Close inspection doors; repair leaks in boiler; unplug hoppers; clean insulators	Regular preventive maintenance will alleviate these problems

Wire buildup is not usually due to insufficient rapping but to some other factor, such as process change. Uniform buildup can have the effect of creating a larger diameter wire and requiring higher voltage to initiate ground current. A sudden failure or rash of failures can occur from process changes or extreme malfunction in the ESP.

In a rigid frame design, one broken wire does not result in the failure of the entire bus section. High "G" forces in rapping rigid wire frames can lead to premature mechanical failure near the impact point, at connection to support members, sharp bends, and welded connections. High resistivity dusts are very tenacious and need high rapping forces, thus requiring European design.

Rappers (Vibrators/Impulse)--
Impulse electric or pneumatic rappers are more successful in difficult rapping applications than are electric vibrators.

Pneumatic rappers are beneficial in warm, high-moisture ambient environments. If the temperature falls below freezing, however, pneumatic is not recommended because the entrapped moisture in the air lines may freeze unless adequate air dryers are installed.

Rappers (Mechanical Failures)--
Failures occur in the transmission hardware at the interface of a high-strength alloy and mild steel components.

Poor quality of welds from rapper to support frame may result in cracks; frequently encountered weld types are butt joint, cup joint, gusset joint. Good welding practice is to preheat and postheat.

Rapper binds due to misalignment during installation.

Rapper rod seizure occurs from the leakage and improper seals and dust accumulation.

Collector Electrodes--
Plate corrosion results from gas temperature going below dew point and allowing condensation to occur on lower portion of plate. Air leakage into hopper also produces condensation and corrosion on electrodes.

Mechanical failure at supports can occur from poor construction or assembly and overrapping.

Dust Removal System--

Plugging is the main problem and could result from moisture condensation, with its associated dust agglomeration and caking within the hopper. Dust buildup will eventually contact high-voltage electrode frame and short out high-voltage bus sections, misalign electrodes, and form clinkers by ash fusion from the high-voltage current. Hopper and heaters should be operated continuously to avoid buildup.

Housing and Casing--

Air leaks and infiltration (causing corrosion) can occur at expansion joints, slip joints, and inlet/outlet ducts. Should acid/gas temperature go below dew point, condensation can also result in corrosion.

Coupons of aluminum, corten, and stainless steel are often placed inside the unit to study the corrosion resistance of these materials. Coatings such as coal tar epoxy are used to eliminate corrosion.

Insulators--

Dust and/or moisture accumulation on the insulator surface could lead to electrical arc-over as evidenced by tracking. Excessive arc-over could result in insulator cracking or breakage. Filtered and heated purge air prevents fouling of the insulators, bus bars, and bus ducts.

4.2.7 Spare Parts

The ESP manufacturer should supply a list of recommended spare parts. The spare parts required are usually those associated with moving and rotating components. A summary list of replacement parts is provided in Table 4. The user of the equipment will develop a spare parts inventory according to the type and frequency of part failure.

4.2.8 Troubleshooting Program

Should a major problem bring the need for a thorough survey, a multiphase troubleshooting program as outlined is recommended. An actual case history of such a program is provided in Appendix A.

4.2.9 Troubleshooting Procedures

Guidelines for troubleshooting and correcting ESP malfunctions are provided in Table 5. This chart is used as a diagnostic aid to troubleshoot specific symptoms. A supplementary approach to evaluate operational problems is to interpret abnormal electrical meter readings from the ESP control cabinet. Table 6 is a general guide prepared for this purpose.

TABLE 4. REPLACEMENT PARTS FOR ELECTROSTATIC PRECIPITATORS

Discharge electrodes:	Wires, weights, fastening hardware
Collector electrodes:	Antisway insulator
T/R set:	Insulators, rectifiers
Voltage controller:	Printed circuit boards, switches, relays, fuses.
Dust handling system:	Level indicators, motor bearings, seals, solenoids.
Insulator compartment ventilation system:	Filters, motors, heating elements
General supplies:	Gasketing, silicone grease, chamois cloth, lubricants, special tools

TABLE 5. TYPICAL TROUBLESHOOTING CHART FOR AN ELECTROSTATIC PRECIPITATOR

Symptom	Cause	Remedy
No primary voltage. No primary current. No precipitator current. Vent fan on. Alarm energized.	Overload condition	Check overload relay settings. Check wiring components.
	Misadjustment of current limit control	Check adjustment of current limit control setting.
	Overdrive of SCR's	Check signal from firing circuit module.
No primary voltage. No primary current. No precipitator current. Vent fan off. Alarm energized.	Relay panel fuse blown	Replace.
	Circuit breaker tripped	Reset circuit breaker.
	Loss of supply power	Check supply to control unit.
Control unit trips out on overcurrent when sparking occurs at high currents.	Circuit breaker defective or incorrectly sized	Check circuit breaker.
	Overload circuit incorrectly set	Reset overload circuit. Check primary power wiring.
	Short circuit condition in primary	
High primary current. No precipitator current.	Transformer or rectifier short	Check transformer and rectifiers.
No primary voltage No primary current. No precipitator current. Vent fan on. Alarm not energized.	SCR and/or diode failure	Replace.
	No firing pulse from firing circuit and/or amplifier	Check signal from firing circuit and/or amplifier.
Same as above, even after replacing components or subpanels, changing wires, or repair.	SCR's being fired out of phase	Reverse input wires.

(continued)

Table 5 (continued)

Symptom	Cause	Remedy
Low primary voltage. High secondary current.	Short circuit in secondary circuit or precipitator	Check wiring and components in H.V. circuit and pipe and guard. Check precipitator for: Interior dust buildup full hoppers Broken wires Ground switch left on Ground jumper left on Foreign material on H.V. frame or wires Broken insulators.
Abnormally low precipitator current and primary voltage with no sparking.	Misadjustment of current and/or voltage limit controls	Check settings of current and voltage limit controls.
	Misadjustment of firing circuit control	Turn to maximum (clockwise) and check setting of current and voltage limit controls.
Spark meter reads high -- off scale. Low primary voltage and current.	Continuous conduction of spark counting circuit	Deenergize, allow integrating capacitor to discharge, and reenergize.
No spark rate indication.	Spark counter counting 60 cycles peak	Readjust.
	Failure	Replace.
Spark meter reads high; primary voltage and current very unstable.	Misadjustment of PC-501	Readjust.
	Loss of limiting control	Replace.
Neither spark rate, current, nor voltage at maximum.	Misadjustment of PC-501	Readjust setting.
	Failure	Replace.
	Failure of signal circuits.	Check signal circuits.

(continued)

Table 5 (continued)

Symptom	Cause	Remedy
No spark rate indication; voltmeter and ammeter unstable, indicating sparking.	Failure of spark meter	Replace spark meter.
	Failure of integrating capacitor	Replace capacitor.
	Spark counter sensitivity too low	Readjust.
No response to current limit adjustment; however, does respond to other adjustments.	Controlling on spark rate or voltage limit	None needed if unit is operating at maximum spark rate or voltage adjustment. Reset voltage or spark rate if neither is at maximum.
	Failure	Replace.
	Current signal defective	Check signal circuit.
No response to voltage limit adjustment; however, does respond to current adjustment.	Controlling on current limit or spark rate	None needed if unit is operating at maximum current or spark rate. Reset current and spark rate adjustment if neither is at maximum
	Voltage signal defective	Check voltage signal circuit.
	Failure	Replace.
No response to spark rate adjustment; however, does respond to other adjustment.	Controlling on voltage or current	None needed if unit is operating at maximum voltage or current. Reset voltage and current adjustment if neither is at maximum.
	Failure	Replace.

(continued)

Table 5 (continued)

Symptom	Cause	Remedy
Precipitator current low with respect to primary current. Low or no voltage across ground return resistors.	Surge arrestors shorted	Reset or replace surge arrestors.
	H.V. rectifiers failed	Replace H.V. rectifiers.
	H.V. transformer failed	Replace H.V. transformer.
	Ground or partial ground in the ground return circuit.	Repair ground return circuit.

TABLE 6. GUIDE FOR INTERPRETING ABNORMAL METER READINGS

1. Increasing gas temperature results in a corresponding voltage increase and current decrease (arcing can develop). Conversely, decreasing gas temperature will result in voltage diminution and current increase.

2. An increase in moisture content at given process conditions will result in a relatively small increase in current and voltage levels.

3. Excessive sparkover may result from additional moisture and is indicated by a voltage increase.

4. Grain loading increase will somewhat elevate voltages and reduce current.

5. A particle size decrease will be reflected in a voltage rise and diminished current.

6. Gas velocity (flow rate) increase will tend to increase voltages and depress current.

7. Air leakage may cause additional sparkover and reduced voltage.

8. During normal operation for individual power supplies, the voltage/current ratio will decrease in the direction of gas flow.

9. Hopper overflow will result in shorting and drastically reduced voltage and current increase.

10. Broken, swinging discharge electrode wires result in violent arcing and extreme and erratic meter behavior.

11. A T/R short results in zero voltage and high current.

12. Buildup on wires is accompanied by a voltage increase to maintain same current level.

13. Buildup on plates is accompanied by a voltage decrease to maintain same current level.

4.3 WET ELECTROSTATIC PRECIPITATORS

The functional design of wet ESP's is similar to that of the dry ESP's; the main difference is that the collected particulates are dislodged from the collecting surface by continuous water spray or by a cascading water sheet. The wet electrostatic precipitators (WEP) now in use are of the plate-, concentric-plate-, or pipe-type design. Wet precipitators find application in the aluminum, iron, steel, and glass industries.

According to the application, the WEP is an attractive alternative to the wet scrubber, ESP, and baghouse. For example, a condensible, submicron hydrocarbon emission can easily be removed by WEP rather than by using a high-energy venturi scrubber. The problem of high or low dust resistivity is eliminated in WEP's because the collector electrode is continuously flushed. The resistivity of the water film (which is very low) is the governing factor in the dust discharging process, not the resistivity of a dust layer formed by collected particulate.

The gas to be treated by a WEP must be saturated with water vapor before it enters the unit. Consequently, the performance of the WEP is not very sensitive to gas temperature. Further, since the internal components are continuously washed, the WEP will also remove gaseous pollution so long as the gaseous component is soluble in the washing liquor.

Many of the components of a WEP are similar to those of a dry ESP; therefore, many of the remarks made in Sections 4.1.1 through 4.1.7 are also applicable.

4.4 WET ELECTROSTATIC PRECIPITATOR OPERATION AND MAINTENANCE

As one would expect, the WEP has a high potential for corrosion and scaling and requires a water treatment system. If the wash liquor is to be recycled through the WEP, which in most cases is necessary to save on water consumption, the same water treatment methods used with scrubbers must be applied (see Section 5). Concentration of suspended and dissolved solids must be maintained, in addition to pH control. The clarification of solids must be sufficient to minimize spray nozzle plugging and buildup of recycled materials on the internal members of the precipitator. If condensible materials are being collected, means for removing them must be provided (such as skimming devices or methods for sludge removal).

The dissolved solids concentration must be maintained at a steady and acceptable level, either by the right amount of purging, by chemical treatment, or both.

4.4.1 Pre-Startup Inspection

Before starting up the WEP, a thorough inspection of the system is required. The procedure and checklist to follow is provided in 4.2.1, with the exception of items applying to the water cleaning system.

Water Cleaning System:

Turn on water cleaning system and check all pipe connections for leaks.

Check for adequate water flow.

Check individual water line pressure

Check angles and direction of nozzle spray. Correct nozzle positioning is necessary to obtain coverage of precipitator internals.

Inspect drain system to ensure that wastewater drains freely.

Check for adequate clearance between piping and high voltage system.

A WEP preoperation and inspection checklist can be compiled from Figures 6 (page 56) and 8 (page 88).

4.4.2 Routine Startup

Follow procedure in 4.2.2, except replace Items 3, 4, and 5 with activation of spray system as given in 5.2.2, Items 1 through 6.

4.4.3 Routine Inspection and Maintenance During Operation

Only visual inspection of the external components of the system is possible during operation. Therefore, only instrumented operational parameters can be observed, along with inspection of electromechanical equipment and structural components. A routine daily inspection checklist for a WEP can be made from Figure 7 (page 59) excluding the entry for Rappers and Figure 9 (page 91) excluding the entry for Mist Eliminator. Since actual inspection and maintenance practices are quite specific to the particular system used, a tailormade checklist should be prepared by the user and vendor.

4.4.4 Routine Shutdown

Follow 4.2.4, Items 1, 2 and 3; replace 4 with Items 3, 4, 5, and 6 from 5.2.4; then proceed with 5, 6, 7, and 8 from 4.2.4.

4.4.5 Common Malfunctions

Scaling, buildup, and corrosion are commonplace in WEP's. These conditions are prevalent not only within the liquor recirculating system, but also in the electrostatic precipitator housing. Liquor clarification and chemical treatment are critical to WEP performance. Thorough familiarity with scrubber and dry ESP troubleshooting procedures are necessary in order to properly diagnose WEP malfunction and poor performance.

A case history of a WEP is provided in Appendix A, which outlines the use of the multiphase troubleshooting program.

SECTION 5

TECHNICAL ASPECTS OF THE DESIGN, OPERATION, AND MAINTENANCE OF SCRUBBERS

Wet scrubbers are air pollution control devices that provide an environment to enable flue gas contaminants to contact impaction targets, generally water droplets. The wetted contaminant impinges on collection surfaces (entrainment separators) and removes the contaminant-laden droplets from the gas stream. Although there are devices that use mechanisms such as steam condensation, electrostatic charging, or sonic agglomeration in conjunction with conventional scrubber mechanisms, they will not be discussed here because applications are few and the technology is still in the early stages of development. The emphasis in this section is also focused on particulate removal, not gaseous removal.

The collection efficiency of wet scrubbers varies according to design and total power expended both in forcing the gases through the collector and in generating liquid contact surfaces (droplets). Scrubber manufacturers promote their product according to such parameters as particle size collection efficiency and mass collection efficiency.

The scrubbing liquid is introduced into the scrubber in many ways, the most frequent of which are listed below:

Fine spray nozzles
Coarse spray nozzles
Very coarse spray nozzles (>3/4-in. pipe)
Overflow weir
Impingement of gas onto liquid pool
Introduction of gas under surface of liquid pool

The liquid sprays can be operated at low or high pressure and introduced into the airstream countercurrent, cocurrent, or across the direction of gas flow.

The classification of scrubbers is difficult because so many designs are available. As an example, a list is given in Table 7.

TABLE 7. SCRUBBER CLASSIFICATIONS

Basic type	Specific type
Impingement baffle	Tangential inlet wet cyclone Spiral baffle wet cyclone Single plate Multiple plate
Packed tower	Fixed bed Moving bed Flooded bed Multiple bed
Submerged orifice	Wide slot Circular slot Multiple slot
Venturi (Preformed spray) (Gas-atomized spray)	High pressure Medium spray Low pressure Flooded disc
Miscellaneous and combination scrubbers	Crossflow packed Centrifugal fan Multiple venturi Combination venturi Combination fan

Other designs are presently in use or being marketed that may not have been mentioned in this table. One of the most popular devices available is the high pressure drop venturi, because of its ability to control emissions of submicron particle size distribution.

When the airstream emerges from the scrubber vessel, it contains billions of contaminant-laden droplets, which must be removed from the airstream before being emitted to the atmosphere. For this purpose, entrainment separators (demisters) are supplied, which come in numerous designs and configurations. Frequently encountered types are listed below:

Centrifugal
Vane axial centrifugal
Zigzag baffle
Chevron
Staggered channel
Knitted wire mesh
Geometric woven mesh

The droplets captured in the entrainment separator coalesce and run off into a liquid reservoir (sump). This liquid is usually chemically or physically treated for stabilization; a portion is recycled back to the scrubber, and a portion is removed (blowdown). Makeup liquid is provided somewhere in the liquid circuit to compensate for blowdown.

The collected contaminant in the spent liquors must be concentrated before final disposal is performed. The common types of waste disposal equipment are listed below:

Settling tank
Settling pond
Clarifier
Thickener
Vacuum filtration
Liquid cyclone
Continuous centrifugal

The contaminant-laden liquors are further concentrated by such treatments as coagulation, flocculation, chemical precipitation, ion exchange, and desalting. The degree of treatment depends upon the methods of disposal or recycling and upon state and Federal regulations. The relative merits of the wastewater disposal system are beyond the scope of this report, but the user of scrubbers must be sure that these systems are operated and maintained in an appropriate fashion.

5.1 SCRUBBER COMPONENTS AND OPERATIONAL PARAMETERS

The scrubbing system is composed of exhaust hoods and ducts handling airborne contaminant. Gas pretreatment equipment may be required for coarse contaminant removal and for cooling before the contaminant enters the scrubber vessel. The contaminant-laden droplets are removed by the entrainment separators. The clean gas is then passed through an induced-draft fan and up the stack. Forced-draft fans upstream of the scrubber are also used. The associated components for liquor handling are the pumps, piping, valves, motor, and fans. The key parameters affecting the particulate collection are:

Velocity/gas flow rate
Liquid-to-gas ratio
Particle size distribution
Pressure drop

5.1.1 Velocity/Gas Flow Rate

The collection efficiency of most scrubbers depends on the velocity of the gas stream through the liquid-contacting section of the scrubber vessel. The relative velocity between washing liquids (droplets) and particulates is critical to contaminant collection. In the case of high-energy venturi scrubbers, a velocity of 40,000 ft/min can be delivered. Fine droplet size and high density lead to increased removal efficiency.

When a high-temperature gas stream enters the scrubber, the volumetric flow rate diminishes accordingly (based on the temperature of the scrubber liquid) because the gas is being cooled by the scrubber liquors. In poorly designed systems, as the particulate laden droplets enter from the recycled liquors or the impaction process and traverse the vessel, the particulates may become airborne again if sufficient evaporative cooling takes place. Should this occur, pretreatment with clean liquors (for quenching) may be required.

When the system flow rate decreases, the resulting relative velocity may not be sufficient to collect the prescribed amount of contaminant and emissions will increase. Similarly, a decrease in liquid flow rate could produce insufficient cleaning.

5.1.2 Liquid-to-Gas Ratio

The liquid-to-gas flow rate (L/G) is a calculated value, reflecting the liquid recycling rate (gal/min) for every 1000 ft^3 of gas cleaned. Typical values range from 2 to 40, and are a function of inlet gas temperature, inlet solids content, and method of water introduction. High L/G ratios are used for high-temperature and high-grain loadings. Should the L/G ratio fall below design values, collection efficiency will diminish.

5.1.3 Pressure Drop

The pressure drop across a scrubber includes the energy loss across the liquid gas contacting section and entrainment separator, with the former accounting for most of the pressure loss. A low pressure drop scrubber ranges from 2 to 10 in. H_2O; a medium from 10 to 30 in. H_2O; and a high, 30 and above. The higher the pressure drop, the greater the collection efficiency for both particle size and concentration.

5.1.4 Particle Size Distribution

Performance of a scrubber depends on the gas stream particle size distribution. Efficient collection of submicron contaminant challenges the application of any type of control equipment. High-energy venturi scrubbers are designed for submicron contaminant collection.

5.1.5 Scrubber Vessel

The ultimate goal of the scrubber, regardless of its design, is to provide the greatest number of droplets to the contaminant stream in as optimum a fashion as possible. Regardless of the method used to introduce the liquid into the vessel, the wet scrubber requires a uniform and consistent liquid distribution pattern. One method to accomplish this is with a spray nozzle. The spray nozzle used in wet scrubbers may be of the pressure type (hollow and solid cone, impingement, and impact); rotating (spinning atomizers); or other miscellaneous configurations. Spray nozzles frequently wear or clog, producing an uneven liquid pattern and requiring replacement. Carbide nozzle tips, which are abrasion resistant, can be supplied with standard stainless steel nozzles. Titanium and ceramic nozzles are now becoming more prevalent in scrubber vessels. Weir box distribution, on the other hand, requires little maintenance after initial leveling.

Other than nozzle abrasion, the presence of dry/wet zones at the inlet to the vessel or in some other part produces build-up and eventually causes malfunction. Liquid distribution components (nozzles, weirs) must be provided at the interface to avoid this problem.

When the vessel is operated under high negative pressure, the liquid within the associated components rises an equivalent height. Therefore, all joints must be sealed to withstand this pressure; gasketing and hardware must also be corrosion resistant, especially since the single most prevalent problem in scrubbers is material failure due to corrosion. Corrosion occurs because most scrubber applications are associated with acid gas streams and, upon contact with the scrubbing liquors, form corrosive liquids. The scrubber vessel is thus usually fabricated with special alloy steels (stainless 304/316, Hastalloy, Inconel) or fiberglass, or it may contain liners of rubber or plastic. Should high velocities exist within the vessel, as with the venturis, the abrasion-resistant qualities of the materials must also be considered.

Another frequently encountered problem in scrubbers is scaling. Scaling results from improper chemical balance in the system and is usually corrected by the proper chemical treatment of the washing liquors, most often by pH control.

5.1.6 Entrainment Separators

Upon leaving the contaminant washing section, the gas stream contains contaminant-laden droplets. The droplets are removed from the gas stream by an "entrainment separator," which provides the droplets with impingement surface or imparts centrifugal forces that remove the droplets from the gas stream. The common types available are listed on page 80. The most important factor in choosing and designing an entrainment separator is droplet size removal efficiency. Other than for centrifugal separation, the droplet velocity is not especially critical because the droplets usually possess sufficient inertia and thus do not change direction or follow the air streamlines through the separator; instead they collide on one of the numerous obstructions (baffles, wires, chevrons) in their path. The droplets coalesce upon collision in the separator and form sheets of liquid, which drain off into liquid reservoirs or sumps.

Because the droplets contain contaminant, particulate buildup is likely to occur in the mist eliminator. This condition is often avoided by using an intermittent or continuous liquid wash for the mesh, channel, chevron, or baffles. The wash system is usually composed of low-pressure nozzles with cocurrent and/or countercurrent flow, and the system uses recycled liquors or fresh water for cleansing. An increasing pressure drop across the separator is usually caused by buildup. Mesh separators are most prone to plugging; channel, chevrons, and baffles are next; and the centrifugal separators are least likely to plug. Materials of construction of the separator are usually steel or plastic. A major factor when considering using plastic is the possibility of meltdown should the scrubber lose liquid pumping capability, thus exposing the mist media to the high-temperature gas stream. Although temperature controllers upstream of the scrubber can shut the blower down, the blower slowly diminishes rotating, therefore pulling the unwanted hot gases through the media. Hence the use of plastic media in high-temperature applications should be carefully evaluated.

The centrifugal separators allow the droplet-laden gas to enter tangentially, which imparts a centrifugal force on the droplets. As the gas spins through the unit, the liquid droplets are forced outward toward the wall. The performance of this type of separator is extremely dependent on the flow rate within the unit. A decrease in flow could result in liquid droplet carryover to the fan and stack.

5.1.7 Liquor Reservoir (Sump)

Liquid runoff from the entrainment separator is captured in the sump, which is integrally mounted to the scrubber vessel. It may have a pyramidal shape or some other suitable design. The contaminant within the sump settles and is pumped away for additional treatment. Some sump designs incorporate the scrubber pump liquid pickup from the sump itself. In this case, the piping pickup points should be of sufficient elevation to avoid entraining the high solids content of the liquors in the sump bottom. Excessive sludge buildup in the sump often leads to system shutdown and supplementary cleaning.

5.1.8 Pumps

Scrubber pumps (usually centrifugal) may be operated at low or high pressure and flow according to the required means of producing droplets. Pump failure is usually attributed to a combination of abrasion and corrosion, and may be reduced by using appropriate materials of construction for impellers and housing. Some pump protection is provided by inlet strainers; the lower the suspended solids concentration and the more chemically stable the liquids, the more protection is provided.

High-rpm pumps will fail more frequently. Since pumps contain moving parts, they are items of high maintenance. The bearings must be lubricated and inspected regularly, and the pump seals must also be checked frequently. Most pumps are directly coupled to the motor shaft. Belt drives may be required, however, to vary pump rotation (flow).

Insufficient pump suction can cause severe problems. Too high a negative pressure at the eye of the impeller can cause "boiling" of the liquid, cavitation, and severe vibration, leading to erosion of the impeller, noise, and shaking of the pipework. This is especially true with hot or volatile liquids. Under the conditions of maximum flow, the system must have a net positive suction head (NPSH) greater than the NPSH required by the pump. If insufficient NPSH is available from the system, cavitation will occur.

5.1.9 Piping

The piping in scrubber systems handles high solids concentrations and chemically corrosive materials. Erosion and wear tend to occur at sudden changes in pipe cross sections (elbows, reducers). The required elbows and reducers should have thick walls and, in the case of elbows, a wide radius. Materials of construction must provide corrosion and erosion protection. High-pressure piping must also be specified where high-pressure pumps are used. Blind flanges allow for ease of pipe cleanout. Flanged pipe sections and unions also facilitate maintenance. The gasketing material for the flanges must be compatible with the liquors.

5.1.10 Valves

Valves are also subjected to corrosion and erosion. Unless specifically designed for throttling, most valves should be operated in a fully opened or closed position. Valves that experience pressure drop should contain abrasion-resistant linings, especially if the liquors contain a high level of suspended solids. Should valve throttling be necessary, to alleviate wear in the valves and compensate for the change in pressure in the line, orifice plates are installed upstream of the valve to reduce the pressure rise due to throttling.

5.1.11 Fans

Scrubber fans can be positioned either upstream (forced draft) or downstream (induced draft) of the vessel. Centrifugal fans are typically used, and experience corrosion and mechanical stress. When the fan is used in a forced-draft capacity, it handles high concentrations of contaminant and can experience abrasion, caking, and buildup. Most scrubber applications use the fan in an induced-draft configuration, therefore handling moisture-saturated air. Some buildup does occur in the fan wheel; should contaminant flake off, imbalance and vibration could occur. High negative pressure fans, especially those used for venturi scrubbers, exhibit extreme mechanical stress because of the high fan tip speeds. The high mechanical stresses, coupled with corrosive gases, often result in stress corrosion and cracking. Abrasion and corrosion resistant fan wheels and linings must be used in such an environment. Fan drains must be provided to remove captured liquid.

5.1.12 Instrumentation

The two types of instrumentation necessary for scrubber systems are safety and performance monitoring:

Safety:

- High temperature interlocks, which actuate pumps for auxiliary recycling and for additional water
- High temperature controls to activate the scrubber bypass system
- Low liquid level alarms and control systems for auxiliary pumps
- Automatic fan controls to activate the bypass system if the blower fails
- Fan vibration indicator and alarm shutoff system
- Fan and bearing high temperature alarm and shutoff

Performance monitoring:

- Discharge pressures and flows on all pumps
- Recycle blowdown and makeup flow
- Pressure drop across scrubber, cleansing section, mist eliminator, and entire scrubber
- Inlet static fan pressure, voltage, and amperage
- pH meters/recorder and low level alarm
- Inlet and saturated gas temperatures
- Suspended solids monitor

The safety interlocks protect equipment and personnel, and the performance monitoring instrumentation effects reliable operation and forecast malfunctions.

5.1.13 Conclusions

Because all component surfaces are wetted, in scrubber applications corrosion can become a substantial problem. Therefore, corrosion-resistant materials must be used in the piping, pumps, and blowers; indeed, most of the scrubber system must use these materials. In the scrubber vessel, where high velocities are present, erosion may occur, requiring the use of proper materials of construction. Properly irrigated entrainment separators are also necessary, and will effectively minimize contaminant buildup. Adequate monitoring instrumentation is crucial to equipment operation and performance. If not in place, it should be procured and installed.

5.2 SCRUBBER OPERATION AND MAINTENANCE

Regardless of the reason for scrubber shutdown, a well-defined inspection program should be followed before commencing startup. Preoperation and inspection guidelines are given below, followed by procedures for routine startup, inspection and maintenance during operation, and routine shutdown. Guidelines for maintenance during shutdown and for detecting common malfunctions are also described.

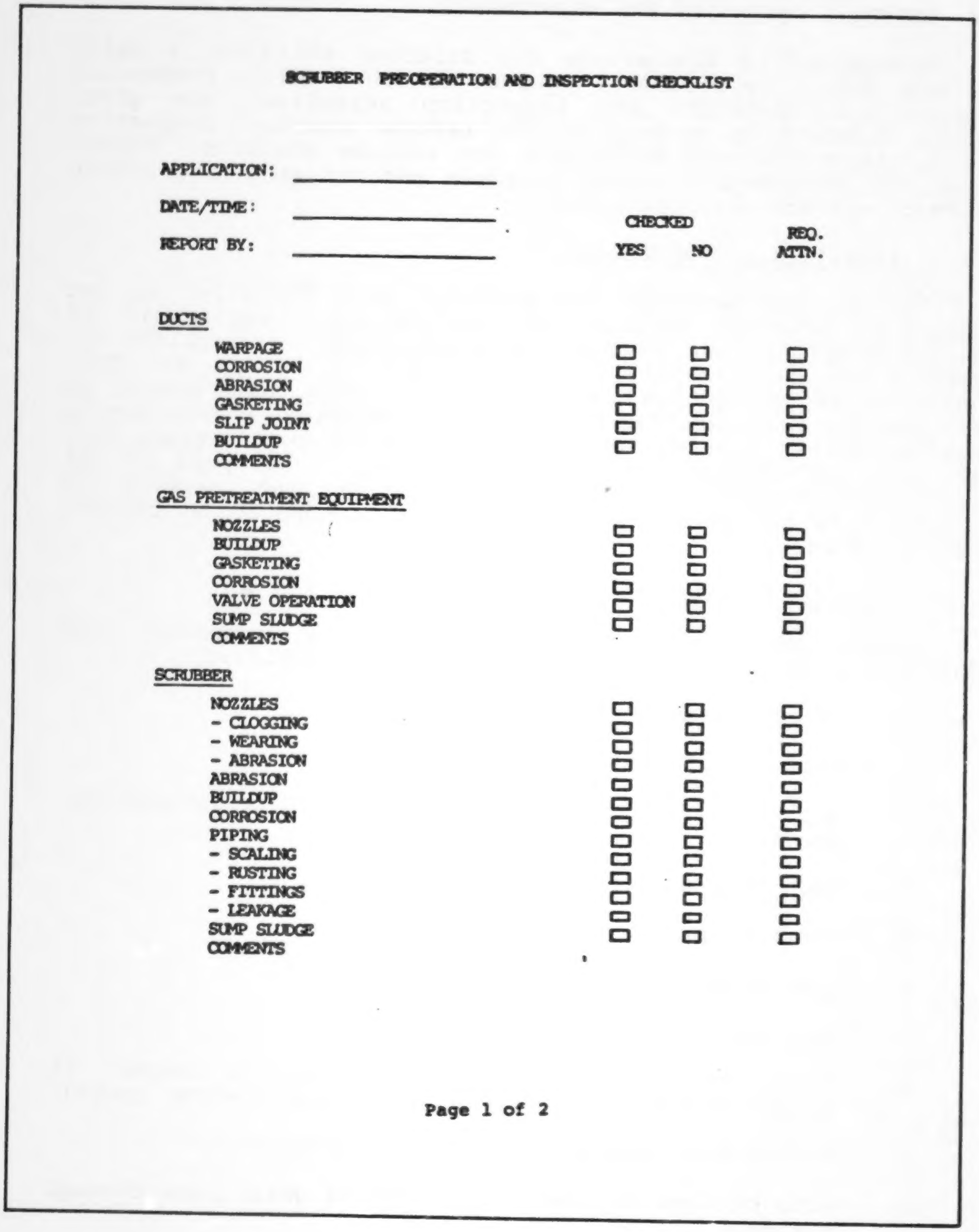
5.2.1 Pre-Startup Inspection

Whether the scrubber has recently been installed or has undergone internal service and maintenance, before it is "buttoned up" it must be thoroughly inspected. A checklist for preoperation and inspection is provided in Figure 8. This checklist is to be used as a guideline only, and should be tailored for each specific system. The inspection survey during shutdown should include internal and external observations from the ducts up through the stack. If possible, as part of the pre-startup inspection before the unit is put into service, it is advisable to operate pumps and other components to observe their performance.

5.2.2 Routine Startup

After the scrubber has been thoroughly inspected, the following general startup procedure should be followed:

1. Close all drain valves.
2. Fill vessels to normal level.
3. Activate circuit breakers for all controls and components.
4. Open pump suction valves.
5. Start pumps.
6. Open discharge valves slowly.
7. Open isolation dampers.
8. Start fan (if fan has an inlet control damper, it should normally be closed until fan reaches speed).
9. Record data from monitoring instrumentation.
10. Note changes in monitoring data as gases pass through system.



SCRUBBER PREOPERATION AND INSPECTION CHECKLIST

APPLICATION: ____________

DATE/TIME: ____________

REPORT BY: ____________

	CHECKED		
	YES	NO	REQ. ATTN.
DUCTS			
WARPAGE	☐	☐	☐
CORROSION	☐	☐	☐
ABRASION	☐	☐	☐
GASKETING	☐	☐	☐
SLIP JOINT	☐	☐	☐
BUILDUP	☐	☐	☐
COMMENTS			
GAS PRETREATMENT EQUIPMENT			
NOZZLES	☐	☐	☐
BUILDUP	☐	☐	☐
GASKETING	☐	☐	☐
CORROSION	☐	☐	☐
VALVE OPERATION	☐	☐	☐
SUMP SLUDGE	☐	☐	☐
COMMENTS			
SCRUBBER			
NOZZLES	☐	☐	☐
- CLOGGING	☐	☐	☐
- WEARING	☐	☐	☐
- ABRASION	☐	☐	☐
ABRASION	☐	☐	☐
BUILDUP	☐	☐	☐
CORROSION	☐	☐	☐
PIPING	☐	☐	☐
- SCALING	☐	☐	☐
- RUSTING	☐	☐	☐
- FITTINGS	☐	☐	☐
- LEAKAGE	☐	☐	☐
SUMP SLUDGE	☐	☐	☐
COMMENTS			

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Figure 8. Preoperation and inspection checklist for scrubbers.

	CHECKED		REQ. ATTN
	YES	NO	
MIST ELIMINATOR			
NOZZLES	☐	☐	☐
- CLOGGING	☐	☐	☐
- WEARING	☐	☐	☐
- ABRASION	☐	☐	☐
PIPING	☐	☐	☐
- RUSTING	☐	☐	☐
- PITTING	☐	☐	☐
- LEAKAGE	☐	☐	☐
VALVE OPERATION	☐	☐	☐
CORROSION	☐	☐	☐
COMMENTS			
MIST ELIMINATOR MEDIA			
BUILDUP	☐	☐	☐
CLEANED	☐	☐	☐
REPLACED	☐	☐	☐
COMMENTS			
LIQUOR TREATMENT			
pH CONTROL	☐	☐	☐
- CALIBRATION CHECK	☐	☐	☐
- PROBE BUILDUP	☐	☐	☐
CAUSTIC HOLD TANK	☐	☐	☐
SLUDGE BUILDUP	☐	☐	☐
VALVE OPERATION	☐	☐	☐
PIPING LEAKAGE	☐	☐	☐
COMMENTS			

Page 2 of 2

Figure 8 (continued)

5.2.3 Routine Inspection and Maintenance During Operation

During normal operation, the preoperation checklist (Figure 8) can be used with the instrumentation measurements noted in 5.1.12. A checklist for inspecting an operational scrubber is given in Figure 9. A tailormade operational checklist should be prepared for each specific type of equipment.

5.2.4 Routine Shutdown

A general procedure for scheduled shutdown is outlined below:

1. Stop blower.
2. Isolate scrubber vessel by closing dampers.
3. Shut down makeup water.
4. Allow system to cool.
5. Continue to blow down at normal rate until liquid levels reach pump inlet, and then shut pumps off.
6. Stop all other pumps.
7. Deactivate all circuit breakers.
8. Open access door and use necessary safety procedures for inspection.

5.2.5 Common Malfunctions

Areas on which to focus attention are:

Buildup in wet/dry zones

Clogged nozzles

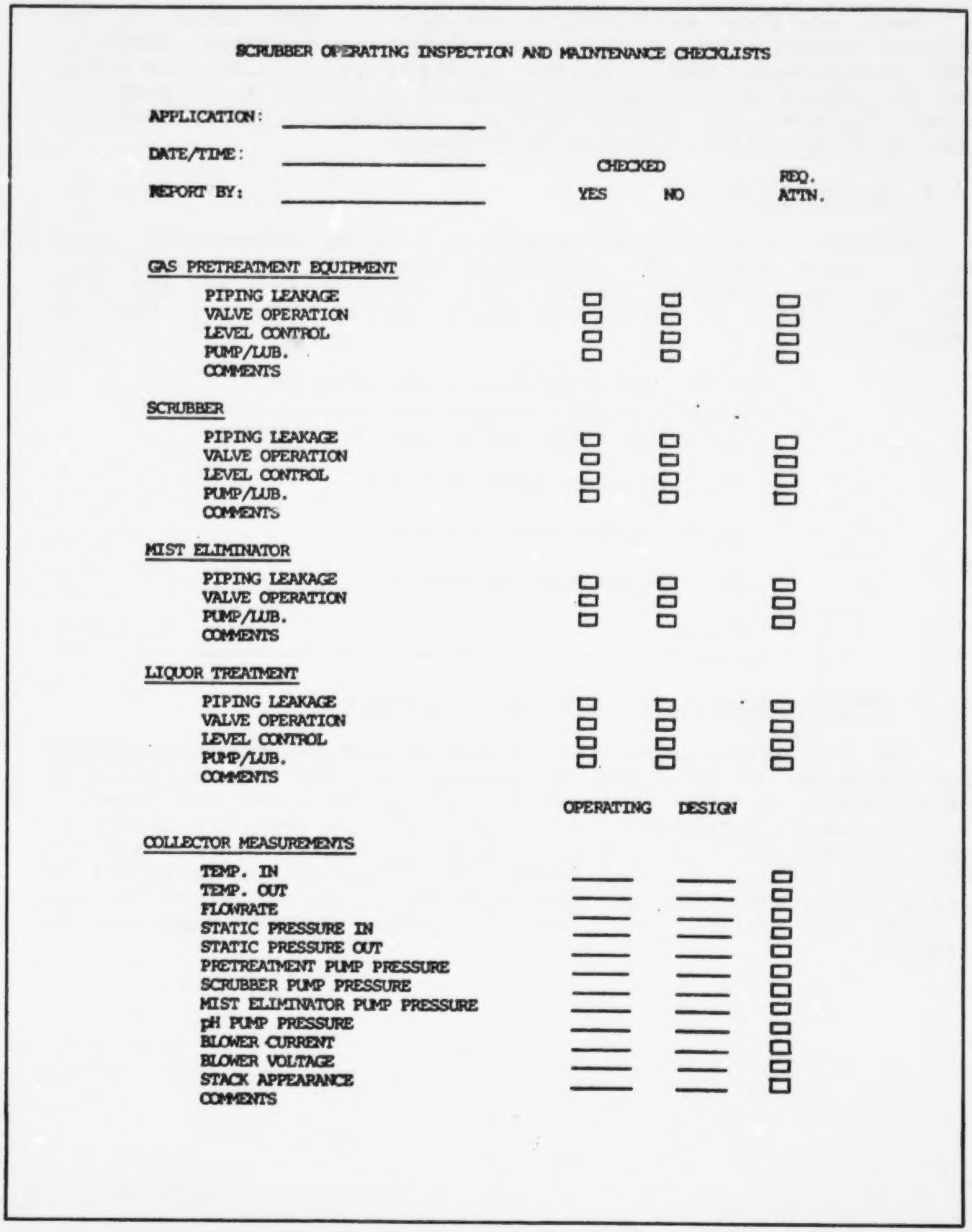
Abrasion in areas of high velocity, throats, orifices, elbows, etc.

Corrosion in ducts, piping, scrubber vessel

Entrainment separator buildup

Fan vibration

Pump wear



SCRUBBER OPERATING INSPECTION AND MAINTENANCE CHECKLISTS

APPLICATION: ______________

DATE/TIME: ______________

REPORT BY: ______________

	CHECKED		
	YES	NO	REQ. ATTN.
GAS PRETREATMENT EQUIPMENT			
PIPING LEAKAGE	☐	☐	☐
VALVE OPERATION	☐	☐	☐
LEVEL CONTROL	☐	☐	☐
PUMP/LUB.	☐	☐	☐
COMMENTS			
SCRUBBER			
PIPING LEAKAGE	☐	☐	☐
VALVE OPERATION	☐	☐	☐
LEVEL CONTROL	☐	☐	☐
PUMP/LUB.	☐	☐	☐
COMMENTS			
MIST ELIMINATOR			
PIPING LEAKAGE	☐	☐	☐
VALVE OPERATION	☐	☐	☐
PUMP/LUB.	☐	☐	☐
COMMENTS			
LIQUOR TREATMENT			
PIPING LEAKAGE	☐	☐	☐
VALVE OPERATION	☐	☐	☐
LEVEL CONTROL	☐	☐	☐
PUMP/LUB.	☐	☐	☐
COMMENTS			

	OPERATING	DESIGN	
COLLECTOR MEASUREMENTS			
TEMP. IN	______	______	☐
TEMP. OUT	______	______	☐
FLOWRATE	______	______	☐
STATIC PRESSURE IN	______	______	☐
STATIC PRESSURE OUT	______	______	☐
PRETREATMENT PUMP PRESSURE	______	______	☐
SCRUBBER PUMP PRESSURE	______	______	☐
MIST ELIMINATOR PUMP PRESSURE	______	______	☐
pH PUMP PRESSURE	______	______	☐
BLOWER CURRENT	______	______	☐
BLOWER VOLTAGE	______	______	☐
STACK APPEARANCE	______	______	☐
COMMENTS			

Figure 9. Operating inspection and maintenance checklist for scrubbers.

Most scrubber malfunctions do not in fact occur in the scrubber vessel, but in the interconnecting ductwork, dampers, fans, centrifugal pumps, valves, and piping. Alarms are often used to signal malfunction of scrubber pressure drop, pump and blower failure, and liquid levels. Changes in process conditions usually affect scrubber performance.

5.2.6 Spare Parts

Scrubber manufacturers supply a list of recommended spare parts. Spare parts for auxiliary equipment, such as pumps, fans, piping, dampers, valves, and instrumentation, are also required. Table 8 shows the spare parts inventory that is recommended.

TABLE 8. REPLACEMENT PARTS FOR SCRUBBERS

Motor (fan, pump, seals, bearings, impeller)
Mist eliminator media (full set)
Gauges (temperature, pressure)
pH probe and required reagent
Piping

5.2.7 Troubleshooting Program and Procedures

The multiphase program to diagnose and troubleshoot operation problems is provided in Appendix A. The troubleshooting chart present in Table 9 gives guidelines for cause and remedies of problems in scrubbers. Although there is some discussion of pumps in this chart, it is by no means exhaustive. Fans are not mentioned because of the extensive scope of troubleshooting guides from manufacturers. The probable cause of fan noise, low or high flow rates, and static pressure are too numerous to itemize.

TABLE 9. TYPICAL TROUBLESHOOTING CHART FOR SCRUBBERS

Symptom	Cause	Remedy
Low pressure drop (scrubber section)	Low airflow rate	Check blower
	Low liquid flow rate	Check pump/nozzles
	Eroded cleaning section	Inspect
	Meters plugged	Clean lines
High pressure drop (scrubber section)	High airflow rate	Check blower
	Plugging in ducts or scrubber	Inspect
Low pressure drop (mist eliminator)	Low airflow rate	Check blower
	Low liquid flow rate	Check pump/nozzles
	Media dislocated	Inspect
High pressure drop (mist eliminator)	High airflow rate	Check blower
	High liquid flow rate	Check pump/nozzles
	Clogging	Inspect/clean
	Flooding	Inspect/drain
High temperature in stack	Insufficient wash liquor	Check pump/nozzle
	Liquid temperature too hot	Check sump temperature
Pump leaks	Packing or seals	Replace
Pump pressure increase	Nozzle plugging	Reduce nozzles
	Valves closed	Open valves
Pump flow rate/ pressure diminished	Impeller wear	Replace
	Nozzle abraded	Replace
	Speed too low	Check motor
	Defective packing	Replace
	Obstruction in piping	Check pipes, strainer, and impeller
Pump noise/heat	Misalignment	Check
	Bearing damage	Replace
	Cavitation	Check
Corrosion	Inadequate neutralization	Check pH control
Erosion	Incompatible materials	Replace materials
	High recycled solids content	Wastewater system

(continued)

TABLE 9 (continued)

Symptom	Cause	Remedy
Scaling	Improper chemical treatment	Change treatment
Pipe plugging	High solids content Abrupt expansion/contraction/bends	Cleaning Change pipe fittings

SECTION 6

TECHNICAL ASPECTS OF THE DESIGN, OPERATIONS, AND MAINTENANCE OF ITEMS COMMON TO ALL AIR POLLUTION CONTROL EQUIPMENT

6.1 INTRODUCTION

Regardless of the nature of the process that generates the airborne contaminant and the method used to clean and filter the gas stream before it is emitted to the atmosphere, the contaminant must be captured and transported efficiently to the control equipment. The hoods, enclosures, and interconnecting ducts used to exhaust contaminant are common to all types of air pollution control equipment. Therefore, exhaust system design is critical to effective control equipment performance.

6.2 EXHAUST DUCTS

Problems often encountered with exhaust systems are insufficient contaminant capture velocity, abrupt duct transitions, long horizontal runs, and incompatible materials of construction. Access doors for cleanout and inspection are often not provided. Door fastening hardware and gasketing should be corrosion resistant and compatible with other materials of construction. Thermal insulation is also necessary if condensation is expected to occur, otherwise corrosion may result.

The presence of duct elbows or shape transitions could lead to abrasion. Duct redesign coupled with baffle plates to achieve a more uniform flow distribution could alleviate the problem along with the installation of appropriate abrasive resistant linings. Flanged ducts are also recommended to facilitate duct cleaning and replacement.

Dampers are sometimes necessary upstream of the control equipment. In this condition, the damper is exposed to the contaminant stream. Buildup in the damper mechanism is likely, and would adversely affect its operation. Abrasion and corrosion are frequently observed. Turbulent flow with its skewed velocity profile created by the damper can seriously affect the performance of downstream blowers and control equipment. If dampers are necessary, flow straighteners may be required prior to allowing the gas stream to enter any sort of operating equipment.

Control equipment ductwork is usually operated under negative pressure. As a consequence, any extraneous air infiltration through cracks, seams, joints, or welds can produce buildup and corrosion due to acid/gas condensation. Proper location of pressure taps and temperature probes with a suitable method for avoiding buildup and clogging is critical for these measurements. The preferred arrangement of these two probes is the use of strip chart recorders. Regular maintenance of the taps and probes is necessary.

6.3 GAS PRETREATMENT

Cyclones may be provided to remove the large particulates, thus reducing contaminant loading to the respective control equipment. The cyclone produces a pressure drop in the system, which (according to the designed collection efficiency) may be substantial. Materials of construction must be compatible with the gas stream.

Temperature reductions of the contaminant stream entering the control equipment can be accomplished by evaporative cooling. Among the configurations available are tangential inlet nozzle sprays, in-line high pressure countercurrent sprays, and sonic nozzle water atomization. Regardless of the configuration, extreme caution must be exercised in maintaining the designated liquid flow (and gas temperature) to avoid the acid/gas dewpoint. The existence of dry/wet zones within treatment equipment can produce buildup and flow choking.

6.4 INLET BAFFLES

Baffles are often installed at the inlet to the control equipment to achieve a more uniform flow distribution. On occasion, the baffles behave as impaction surfaces and accumulate material or exhibit abrasion. If the baffle is not adjustable and these problems occur, the baffle may have to be removed.

6.5 HOPPERS

In either a baghouse or ESP, the collected contaminant is dislodged from the bags or collector plates and falls into the hopper. The hoppers are emptied according to the amount collected. Some type of automatic or semiautomatic method is advisable. The design of the hopper slope and contaminant handling system is based on the physical and chemical properties of the dust. Dust bridging, agglomeration, and mudding can occur in the hopper. Methods for alleviating these problems are hopper vibrators, heaters, fluidizing air, rappers, poke holes, housing insulation, and access doors. Materials of construction are a prime consideration, not only to avoid corrosion but also to ensure structural integrity. Workers frequently rap the hoppers with hammers and pipes to assist the flow of collected dust.

Hoppers are usually operated under negative pressure and need appropriate valving at the bottom apex to allow hopper dust to be removed without admitting air to reentrain dust. A rotary airlock valve suits this purpose; it consists of a paddle wheel that rotates at a given rpm and can discharge materials to a screw conveyor or storage container. New installations should have air locks with wiper blades for each vane to ensure airtight sealing and cleaning. Packing glands and bearings should be set away from the housing to avoid contact with high temperatures.

For low solids flow and nonautomatic installations, slide gates may be used. These gates are used only when the compartment is offline. Air leakage into the hoppers and the associated problems of condensation are prevalent with this method, which is thus not recommended for new installations.

Although costly, the new, larger capacity hoppers are specified with air conveying materials handling systems. These are used when the contaminant is easily handled and has a high solids content. One of the major problems experienced with these systems is moisture condensation and icing in the air lines. Heat tracing, insulation, and moisture separation can alleviate these problems.

When inspecting the hopper, the presence of excessive buildup or bridging may be attributed to a malfunctioning level indicator, nonexistent or inoperative hopper heaters, and vibrators.

6.6 FANS

The fan, along with the ducts, hoods, and air pollution control equipment, make up the pollution control system. The fan generates the suction in the system that draws the air contaminants from the process and passes them to the air pollution control equipment.

The ducts before and after the fan can almost be considered part of the fan itself. These ducts establish smooth airflow into and out of the fan so the fan can do the maximum work moving air. Poor design of these ducts can lead to turbulence and uneven flow pattern at the fan inlets and outlet, and the fan capacity will be lower than expected.

Air density is critical to flow performance. The primary factors affecting density are air temperature and plant altitude above sea level. In either case, the volume capacity of the fan varies with the air density. If the air temperature or altitude increases, the air becomes less dense. For example, a fan moving 20,000 ft^3/min of less dense air is moving less mass than a fan moving the same quantity of "standard air." Consequently, the fan does not have to develop as much static pressure when it is moving less dense air. The horsepower requirements are also lower, because less air mass is being moved.

Fan ratings are developed under ideal laboratory conditions, and typically do not perform as well as the manufacturer predicts. Therefore, fan curves should be heavily relied upon; pitot or S-type velocity probes should be used. Fan blades are designed to be most efficient when air enters in a straight line. Elbows and fan inlet boxes that impart a spin to air entering the fan in the direction of fan rotation decrease the amount of air moved, because the fan blades have to "catch up" to the air before acting on it. If the air spin is opposite to the fan rotation, the output will also be reduced.

Ideally, the fan outlet should be a straight duct length of 5 to 10 duct diameters with no elbows or other interferences. Air discharged from a fan outlet does not normally have a uniform velocity distribution because the mass of air discharged experiences a centrifugal force from the spinning fan wheel, resulting in higher velocities at the outer edge of the outlet than at the inner edge. Several duct diameters downstream from the fan outlet ensure the air velocity returning to near uniform distribution across the duct.

The centrifugal fan (of the radial blade type) is used in systems handling contaminants that are likely to clog and result in fan buildup. The flat radial blades tend to be self cleaning and are built with thick blades to withstand erosion and impact damage from airborne solids. When the material being handled is explosive or flammable, the fan should be manufactured of a nonsparking component and material.

The motors that drive the fans can be direct drive (motor shaft directly coupled to fan shaft) or belt driven. Direct drive fans are more compact and assure constant fan speed because they eliminate belt slippage. Slippage may occur when belt-driven fan drives are not maintained. Fan speeds are thus limited to available motor speeds when the direct drive configuration is used. Belt-drive fans are more flexible when increases (or decreases) in fan speed are required.

The fan may be the only moving part in the air pollution control system; therefore, it requires a great deal of scrutiny during operation and maintenance. If a problem is suspected, duct pressure and velocity readings should be obtained and compared to design specifications. Visual inspection of the ducts may reveal closed dampers or open inspection parts. Problems such as loose fan belts, dirty fan blades, plugged ducts, and overheating fan shaft bearings are frequently encountered in air pollution control equipment systems.

According to the application, space requirements, and costs, the fan may be located either upstream (forced draft) or downstream (induced draft) of the control equipment. Forced-draft fans push air through the system; induced-draft fans draw air through the control equipment. Forced-draft fans experience corrosion and abrasion because they are exposed to heavy dust concentrations. When the contaminant accumulates on the fan blades and a portion then breaks off, vibration and imbalance occur. These fans are usually present in older systems (10 years and greater) where the air pollution control equipment was added to the system and the fan remained the same or was upgraded. This configuration is noticeably present in utility boiler ESP applications. Induced-draft fans are operated on the clean side of the pollution control equipment where they are subject to less contaminant. This configuration is usually present in scrubbers and baghouses.

6.7 EXHAUST STACKS

An exhaust stack on a pollution control system serves two purposes: it helps to disperse the gas stream by discharging the exhausted air above roof level, and it improves fan performance because the uneven velocity distribution at the fan outlet causes a high velocity pressure at the outlet.

All systems should have at least a short, straight stack on the fan. A high stack discharge velocity (3000 ft/min or higher) helps to disperse contaminants, because the air jet action can increase the effective stack height except under severe wind conditions.

If rain entering the stack is a problem, a vertical discharge sleeve that induces ambient airflow and does not block the stack opening is effective in keeping rain out of the stack. The old-style weather cap deflects exhausted air downward and is no longer recommended. Fan discharges should not be directed horizontally to keep rain out because contaminant dispersion is hindered. When the fan is operating, rain entering the stack is not a problem.

6.8 CONCLUSIONS

The simplest way to diagnose a system problem is to inspect and to take pressure and velocity measurements at strategic locations. The visual inspection will reveal closed dampers, open inspection ports, damaged hood and ducts, and malfunctioning components related to the control equipment. Loose fan belts, dirty filters, plugged ducts, or dirty fan blades may be present. Static pressure measurements at hoods, elbows, and on both sides of the control equipment will show the contribution of each to the overall pressure drop in the system and should be compared with previous data. The primary problems usually encountered in systems is insufficient airflow and excessively high contaminant levels.

SECTION 7

INSPECTION, SAFETY, AND MAINTENANCE EQUIPMENT

Various tools and equipment are required for the efficient performance of inspection and maintenance. Table 10 lists the items that are basic to an inspection.

TABLE 10. BASIC INSPECTION AND SAFETY EQUIPMENT

Hard hat
Safety glasses or goggles (nonfogging, no vents)
Suitable gloves
Flashlight
Ear protection
Safety shoes
Dust and gas respirators (disposable)
Tape measure (50 ft)
Paper pad, pen (inspection checklist)
Camera
Body protection (disposable garments, chemical/fire-resistant clothing)

Table 11 lists the testing equipment that should be readily available, and Table 12 lists the hand tools that are needed.

For more extensive maintenance, air-operated power tools are recommended, especially when maintenance is to be performed within the pollution control equipment housing or vessel. Air-operated tools are lighter in weight and more convenient to use. Electrical tools can spark and possibly cause fires or explosions when working inside dusty environments. Table 13 lists the power tools that are recommended, and Table 14 lists items that are required to support the maintenance efforts.

A relatively new way to identify leaking or poorly installed bags is to inject a quantity of fluorescent or highly reflective powder into the baghouse, and then inspect with either black light or a high-intensity lamp. This technique can reveal very small leaks although the need to span large areas is time consuming. Use of the powder is also effective in spotting broken welds or other leaks at joints and seams.

TABLE 11. BASIC TESTING EQUIPMENT

Dial thermometer (50° to 1000°F, 12-in. stem)
U-tube manometer (flexible)
Stopwatch
pH (litmus) paper
Pitot tube (S-type for contaminant streams, 600 ft/min and greater)
Velometer (25 ft/min and greater)
Plastic sample bottles (wide mouth)
Grab sampling detector tubes (Draeger type)
Photo tachometer
Amprobe (a.c. clamp on volt-ohm-ammeter)
Multimeter.

TABLE 12. MAINTENANCE TOOLS

Open-end wrenches
Socket wrenches
Adjustable wrenches
Pipe wrenches
Locking pliers
Pliers (side cutters, slip joint)
Screwdrivers
Hex keys
Hammers
Hacksaw
Knife and shears
Scissors
Calipers
Carpenter's rule
Scraper
Wire brushes
Toolbag and canvas bucket.

TABLE 13. POWER TOOLS

Air screwdriver
Power scissor shears
Impact wrench
Air nut wrench
Air-driven hacksaw
Hydraulic cutters
Pneumatic chisel
Heavy-duty drain cleaner
Blowgun
Air-operated vacuum cleaner (hand held and 55-gal drum type)
Portable air compressor with in-line pressure regulator; filter and moisture trap.

TABLE 14. GENERAL EQUIPMENT

Ladders (wood or fiberglass)
Electric extension cords
Safety (fluorescent) drop lights
Tool pouches
Penetrating lubricant
Fire extinguisher
First aid kit
Protective hand creams
Wood platform truck

In scrubber applications, high-pressure, hot-water cleaning equipment may be used periodically to rejuvenate vessel walls and housing. Rapping equipment may also be required to eliminate pipe scale and buildup.

Stack monitoring instrumentation often utilized for continuous and reliable pollution equipment operation are opacity meters and/or broken bag detectors. This type of instrumentation is usually found in large, high-capacity systems.

SECTION 8

SUMMARY

When management is prevailed upon to purchase, install, operate, and maintain air pollution control equipment, resistance often arises. Regardless of the aesthetic values derived, management considers the equipment to be a large capital expenditure and, after installation, to be a significant contributor to plant overhead. These factors are often coupled with inferior quality hardware that leads ultimately to poor equipment performance, resulting in conflicts between government, industry, and equipment manufacturers.

Management's best approach to reconciling this apparent dilemma is to analyze critically the possibility of a return on the investment in the equipment. Although the ROI is not obvious at the outset, management should explore direct or indirect ways within its operation to effect savings. A return on investment is also calculable for operation and maintenance, by preventing equipment breakdown and loss of production with a well-planned and controlled preventive maintenance program. In this regard, nearly all maintenance activities are human activities, and for the most part, controlled by those individuals executing the work. Even the most explicit inspection checklists, charts, guidelines, methods, and training will not achieve the desired goal unless plant management, engineering, and labor have the commitment and willingness to include an effective operation and maintenance program.

With the understanding that air pollution control equipment is an integral part of the process equipment, discussion of operation and maintenance procedures becomes more palatable to those responsible for its performance.

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APPENDIX A

TROUBLESHOOTING PROGRAM

INTRODUCTION

Frequent equipment malfunction, breakdown, and excessive emissions indicate improper equipment performance. A multiphase program must be implemented to diagnose system problems (hoods, ducts, control equipment, and fan). As a guideline, the following program should be followed:

Phase 1. Problem Identification

This phase should incorporate a detailed inspection of the system during operation and shutdown and culminate with a report listing all observations (positive and negative), providing interpretations of these observations (why things were the way they were); and recommending methods and items to improve performance. Pressure and velocity measurements may also be needed.

Phase 2. Implementation

The recommendations provided in Phase 1 should be implemented after thorough cost and technical analysis and discussion. These recommendations may be in the form of engineering design and modification, component and accessory part replacement, or fabrication of new equipment. Following this aspect of the program, repair and replacement of the procured and fabricated components must be executed. Finally, the entire system must be started up and debugged.

Phase 3. Sampling and Testing

A test must now be performed to evaluate the work. This may be stack sampling or, more often, a pressure and velocity measurement program coupled with close observation of the operation of the system.

Case histories using the multiphase program for a pulse-jet baghouse, dry and wet precipitator, venturi scrubber, and packed tower are presented in this appendix. It should be emphasized that the most effective approach to troubleshooting and diagnosing problems is familiarity with the process and detailed knowledge of the contents of the various troubleshooting guides provided herein and by the equipment manufacturer.

CASE HISTORY

PULSE-JET BAGHOUSE

INTRODUCTION

Excessive emissions from two pulse-jet baghouses on fly ash storage silos were frequently observed. Internal observations of the units indicated bridging of the dust between bags. The conclusion drawn by the user was that the filter medium was incorrectly specified and that the majority of the particle size distribution was submicrometer. Rebagging with different types of media was tried several times, to no avail. The baghouses under consideration were an internal part of an experimental sludge fixation process (see Figure A-1), and their malfunction thus had serious economic implications for the utility. The operators of the fixation process contracted an independent pollution control equipment services and maintenance company to troubleshoot the problem.

Phase 1. Problem Identification

General Comments--

Design, construction, and installation of the two units appeared to be more than satisfactory.

A conscientious housekeeping and maintenance program on the units was obvious.

Observations--

The following observations were made both while the units were operating and while they were shut down.

Airflow, static pressure, temperature, and dimensional data were recorded (Tables A-1, A-2, and A-3).

The baghouses were cleaning air that is discharged from a pneumatic conveying system, which is delivering fly ash from electrostatic precipitator hoppers.

Both systems operate identically and exhibit identical symptoms.

The baghouses operate for up to 50 days with new bags before plugging.

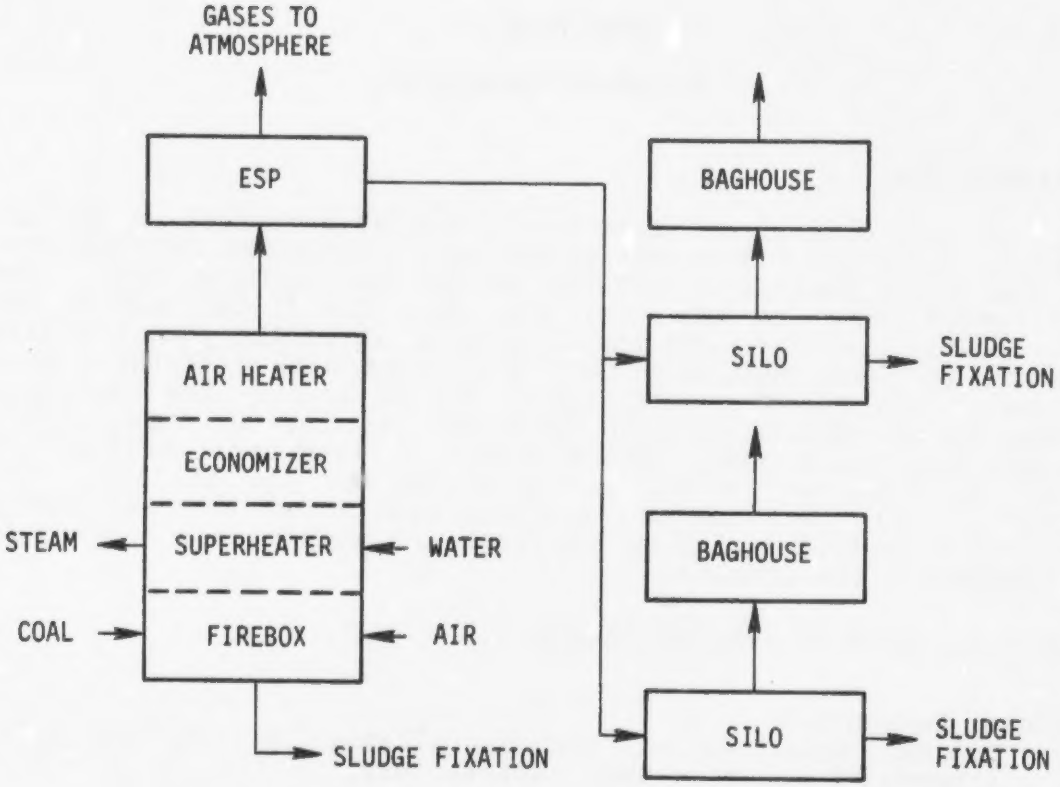
GASES TO ATMOSPHERE
ESP
AIR HEATER
ECONOMIZER
STEAM
SUPERHEATER
WATER
COAL
FIREBOX
AIR
SLUDGE FIXATION
BAGHOUSE
SILO
SLUDGE FIXATION
BAGHOUSE
SILO
SLUDGE FIXATION

Figure A-1. Application of pulse-jet baghouse.

TABLE A-1. SYSTEM PARAMETERS: EAST UNIT (FAN NOT OPERATING)[a]

Ambient air temperature	42°F
Ambient air humidity	Approximately 95% (raining)
Barometer	29.91 in. Hg
Inlet air temperature: dry	62°F
Inlet air temperature: wet	48°F
Outlet air temperature: dry	62°F
Inlet air pressure	3.4 in. H_2O (silo pressure)
Outlet air pressure	1.1 in. H_2O
Bag ΔP	2.3 in. H_2O
Outlet air velocity	3200 ft/min
Outlet dia./area	16 in./1.4 ft^2
Outlet air flow	4480 ft^3/min

[a] Pressure relief vent on this silo is leaking.

TABLE A-2. SYSTEM PARAMETERS: WEST UNIT (FAN NOT OPERATING)

Ambient air temperature	42°F
Ambient air humidity	Approximately 95% (raining)
Barometer	29.91 in. Hg
Inlet air temperature: dry	62°F
Inlet air temperature: wet	49°F
Outlet air temperature: dry	62°F
Inlet air pressure	5.2 in. H_2O (silo pressure)
Outlet air pressure	3.7 in. H_2O
Bag ΔP	1.5 in. H_2O
Outlet air velocity	2700 ft/min
Outlet dia./area	18 in./1.77 ft^2
Outlet airflow	4780 ft^3/min

TABLE A-3. DIMENSIONAL DATA

Header pressure static	100 lb/in^2
Header pressure firing	90 to 95 (adjusted timer to obtain)
Header diameter	3-in. pipe
Header length	8 to 10 ft.
Silo diameter	26 ft
Free space in silo	8 to 10 ft minimum
Particle size distribution	Not applicable
Contaminant	Fly ash from ESP hopper
Diaphragm valve	2009 - 3
Solenoid valve	30
Blow tube diameter	3/4 in.
Port diameter	5/16 in. (no measured)
Bags (glazed polyester)	4½-in. diameter, 99 in. long

One discharge fan has been removed, and the other was not operated. The operator had found that the conveyor blowers alone provide adequate airflow to transport the fly ash to the baghouse, thus enabling the discharge blowers to be shut down.

The bag dimensions and media were correct for this application. The bags fitted properly. The inside surfaces of the bags are very clean, indicating excellent filtering operation and performance.

The bags were well sealed into the tube sheet; no evidence of leaking was observed.

Airflow was adequate and within specifications.

No moisture/dewpoint problems were evident on the bag surface although the operator indicated previous moisture problems on the housing walls.

Air supply to the pulse-jet cleaning system is adequate. The timer design and operation are excellent.

Bag wear is not a problem at this time; previous bag leaks were attributed to punctures made while knocking caked contaminant off the bags during manual cleaning.

Review of a particle size data report suggested that collection and sizing methods used were not proper for airborne fly ash and probably indicate a size distribution much larger than actually present.

The pulse-jet bag cleaning system is not generating an adequate shock wave in the bag when it fires.

The bags were not releasing contaminant during the cleaning pulse. The contaminant agglomerated in large lumps on the dirty side of the bag media (approximately 3/16 inch thick at time of visit).

The buildup on the bags was dry and exhibited no caking characteristics. It released well when the bag was tapped with a finger, leaving a 2-inch-diameter area of clean media.

A spare diaphragm valve and a spare solenoid valve were disassembled and inspected. The size and porting of these valves appeared to be inadequate to obtain a proper shock pulse in the cleaning air jets.

The timer was adjusted to provide a shorter "on" time than previously operated, thus resulting in a plenum pressure drop of 5 to 10 lb/in.^{2}

Interpretations--

The following conclusions were made:

The baghouses were properly sized for this application.

The bag media were appropriate.

The air supply to the cleaning valve system was adequate.

The bags were not releasing contaminant because a sufficient shock wave was not being generated by the cleaning pulse.

A shock wave was not being generated because the valve system was not opening fast enough. The peak-induced pressure was sufficient; however, a quick rise time was needed to generate the necessary shock wave.

The valve system was slow operating because the internal porting in the valve system configuration created too much restriction and thus prevented the right angle valves from "dumping" fast enough.

To create the required shock wave during the cleaning pulse, a rise time of approximately 5 milliseconds was required from valve opening to maximum pressure measured in the blowtube.

Recommendations--

The following corrective actions were recommended.

Replace 3-inch-diameter header with 6-inch.

Replace the diaphragm valves with properly sized, faster acting units.

Replace the solenoid (pilot) valves with units providing a large release port.

Mount the solenoid valves directly on the diaphragm valve release ports.

Rework porting on new valves if necessary to obtain a pressure rise time of approximately 5 milliseconds.

Insulate housings to minimize condensation on inside walls during cold weather operation. (During the inspection, no moisture problem was observed. If the process air drops below 44°F--the present dewpoint--condensation will occur, and thus heaters are required.)

Phase 2. Implementation

The following recommendations were implemented:

A 6-inch header was installed.

Diaphragm and solenoid valves were replaced.

Insulation and strip heaters were installed.

Phase 3. Sampling and Testing

Visual observation of the units indicated no opacity.

No velocity measurements were made on the system.

Followup discussions with the operator indicated continuous and reliable performance.

CASE HISTORY

DRY ELECTROSTATIC PRECIPITATOR

INTRODUCTION

A fertilizer company owned a weighted wire electrostatic precipitator (see Figure A-2) that frequently exhibited excessive sparking and reduced operating voltage. When operating, the system was in compliance for mass particle emission but not for opacity; intermittent "puffing" from the stack was noticed. Several vendors recommended replacement of the existing unit for an approximate installed cost of $500,000. Before the fertilizer manufacturer appropriated this large capital expenditure, the previously described multiphase program was instituted.

Phase 1. Problem Identification

Observations/Interpretations--

The pretreatment simple cyclone was not significantly reducing particulate loading to fan and precipitator. Indication of this was apparent from previously obtained particle size sampling data, which revealed particles approximately 50 percent by weight larger than 10 micrometers.

The product elevator duct bleeds ambient air to the exhaust fan. Aside from the duct handling particulate emissions from the conveyor system, the ambient air with entrained moisture may promote sporadic condensation with subsequent contaminant buildup in the fan and precipitator.

Previous information and onsite observations indicated correlation of stream moisture and opacity. A major portion of the moisture entered the stream through cooling water injection nozzles. The excess moisture was believed to affect particle resistivity.

Frequent temperature changes in process were thought to be reaching dewpoint in the precipitator.

Nine of the 17 rappers (vibrators) were inoperative, malfunctioning, or missing. The complete rapper system contained many inoperable components.

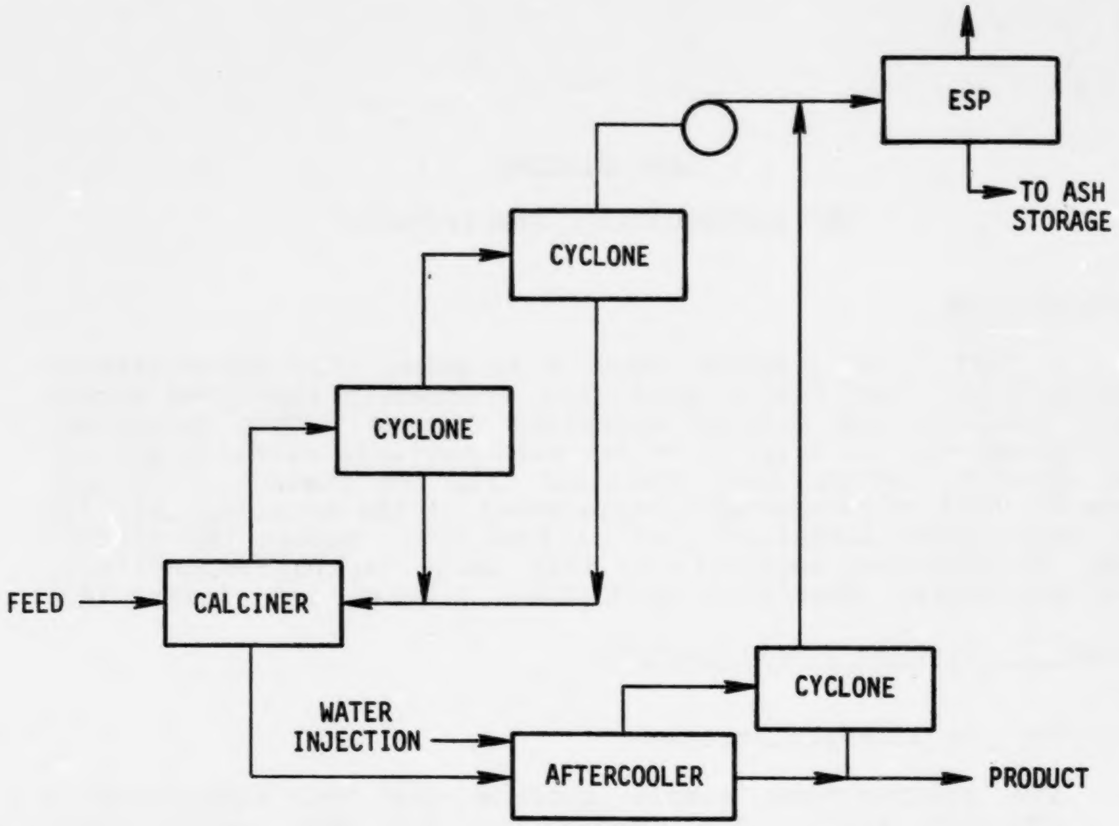
ESP
TO ASH STORAGE
CYCLONE
CYCLONE
FEED
CALCINER
CYCLONE
WATER INJECTION
AFTERCOOLER
PRODUCT

Figure A-2. Application of dry electrostatic precipitator.

Rappers were not sequenced or timed properly.

One high-voltage insulator was cracked.

The wire frame stabilizer insulator was loose.

Gasketing on three bus duct hatches was missing, as were some of the bolts.

Insulator compartment ventilation system contained air leaks and dirty filters; the blower was incapable of overcoming positive pressure in the precipitator housing.

No temperature monitor was present at the inlet of the precipitator.

Recommendations--

A sampling and testing program was devised to characterize the cyclones and precipitator inlet and outlet streams. Parameters measured included grain loading, particle size, moisture, temperature, opacity, and pertinent process variables.

Observe stack opacity while manually controlling water injection.

Renovate, repair, and replace old rappers.

Replace broken insulator.

Secure stabilizer insulators.

Install new gaskets and insulator compartment blower and filter.

Install thermocouple probe upstream of precipitator.

Phase 2. Implementation

Replacement parts and components were requisitioned.

Onsite supervision of repairs was arranged.

Components were repaired or replaced.

Individual precipitator components were operated and tested.

Phase 3. Sampling and Testing

A definite correlation between moisture and opacity was observed. An automatically controlled water cooling system coupled to the inlet precipitator temperature monitor was subsequently installed.

Air load testing was performed to obtain a reference data base.

Inlet and outlet of the precipitator were sampled to determine if the equipment could adequately control process emissions.

Results of testing indicated a reduction in average grain loading from 0.152 gr/dscf to 0.010 gr/dscf. The cost of the overall program was $20,000, thereby saving the company $480,000 in the purchase of new equipment. A preventive maintenance program was subsequently executed as the final phase.

CASE HISTORY

WET ELECTROSTATIC PRECIPITATOR

INTRODUCTION

A wet electrostatic precipitator was installed to remove suspended particulate from the vent gases of a phosphate rock dryer (see Figure A-3). The electrostatically collected material was washed from the plates by water from spray nozzles. A collecting hopper received the effluent, which was carried to a liquor treatment system through a drain system.

The operator of the system experienced frequent opacity violations and attributed the problem to insufficient system voltage. Dry/wet zones produced contaminant buildup, which would occasionally dislodge and either clog drains or short out wires and collector electrodes. The operator of the system asked that an independent survey be made.

Phase 1. Problem Identification

Observations--

Duct buildup in dry/wet zone

Inlet ducts not sloped enough with evidence of pretreatment tangential spray liquid backing upstream into system

Buildup on dry/wet zones in upper WEP support structure adjacent to nozzles

Dry/wet areas on collector electrodes

Spray nozzle clogging

Pipe and housing scale

Sump drains partially clogged with dislodged contaminant

Large amounts of buildup in outlet duct transition

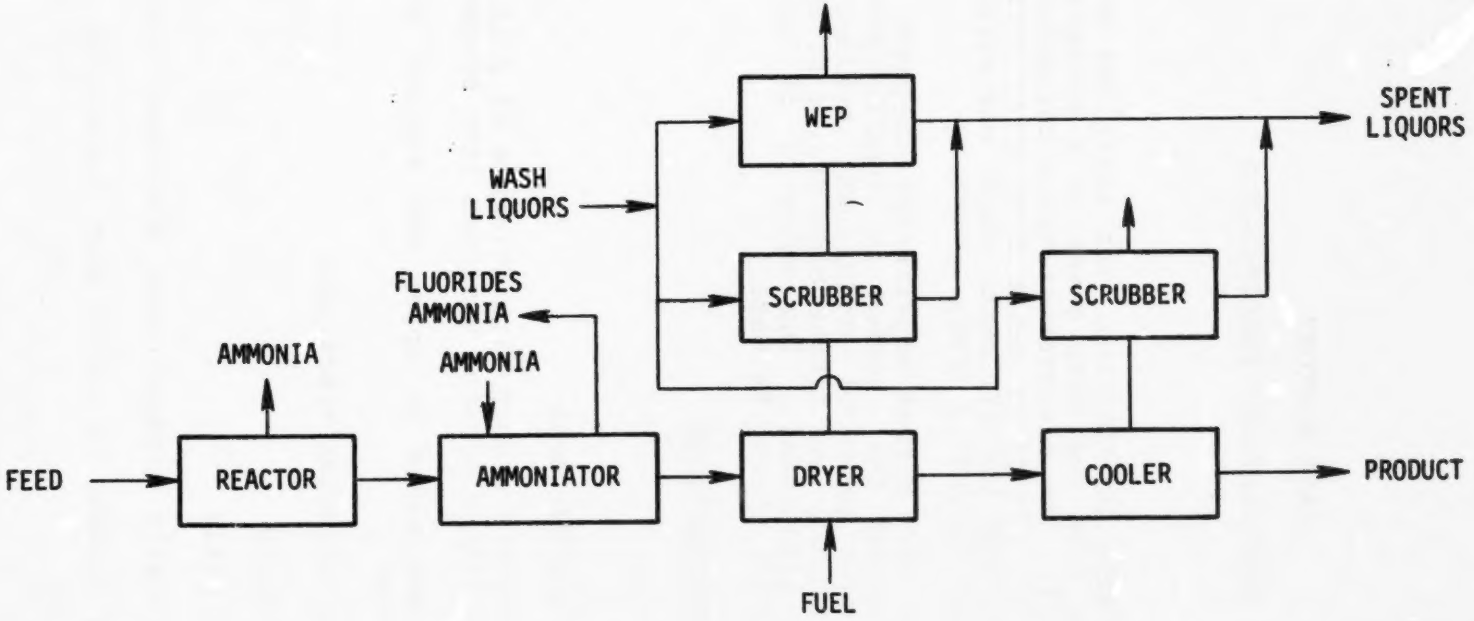
WEP
SPENT LIQUORS
WASH LIQUORS
FLUORIDES AMMONIA
SCRUBBER
SCRUBBER
AMMONIA
AMMONIA
FEED
REACTOR
AMMONIATOR
DRYER
COOLER
PRODUCT
FUEL

Figure A-3. Application of wet electrostatic precipitator.

Recommendations--

Wide angle, high-capacity cocurrent nozzles should be installed to prevent buildup, cleanse ducts properly, and avoid liquid runoff upstream.

Spray nozzle pattern did not coincide with manufacturer's specifications; new, wide-angle, solid cone nozzles were specified.

Pump strainers containing openings slightly smaller than the nozzle orifice should be installed.

pH probe should be relocated to provide a more representative sample of the liquor.

Outlet duct transition cleaning is required.

Phase 2. Implementation

All nozzles and strainers were procured and installed.

pH probe was relocated adjacent to recirculating pump suction side.

Outlet duct transition was cleaned.

Phase 3. Sampling and Testing

Opacity was substantially improved.

Pump pressures and flows remained constant for 3 months.

CASE HISTORY

VENTURI SCRUBBER

INTRODUCTION

A fiberglass manufacturer owned a venturi scrubber that was installed to control the emissions from the forming line (see Figure A-4). Submicrometer emissions produced an opacity of 40 percent and greater. The system was in compliance for grain-loading. Recommendations to improve system performance varied from ionizing the water droplets to replacing the system with wet electrostatic precipitators. Before a major capital investment program was embarked upon, the multiphase program was executed.

Phase 1. Problem Identification

Observations--

Upstream cooling water nozzles, which were mounted tangentially in the ducts, produced a dry/wet zone with large amounts of contaminant buildup.

Venturi spray nozzles were abraded.

Venturi pump impellers were abrading.

High solids content present in recirculating liquors.

Velocity through mesh mist eliminator media was too high.

Recommendations--

Redesign nozzle arrangement to minimize buildup.

Install carbide tip nozzles for venturi spray.

Electroplate abrasive resistant lining on pump impeller.

Perform more frequent sump blowdown and fresh water makeup; install efficient pump strainers.

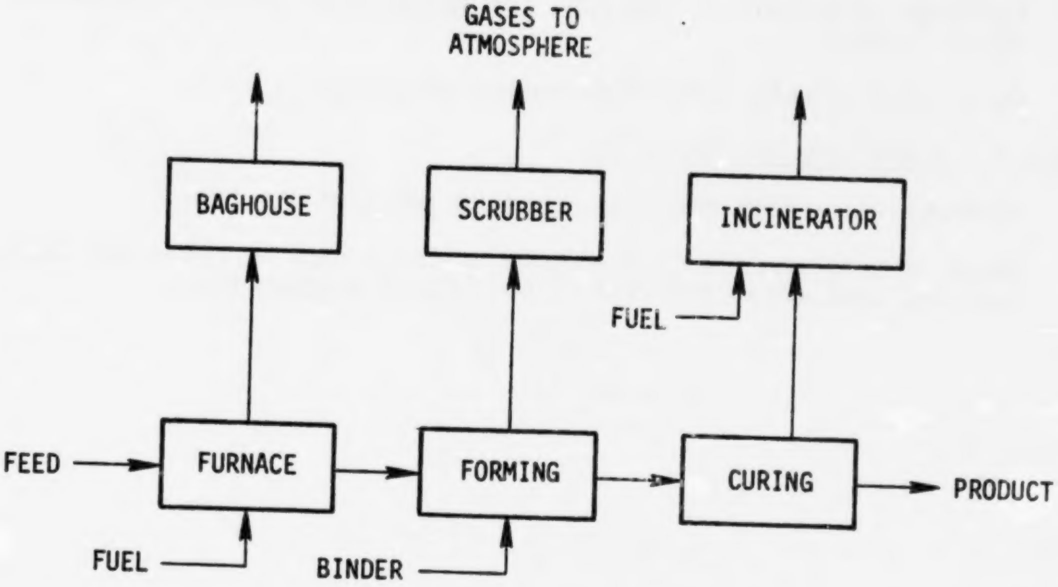
GASES TO ATMOSPHERE
BAGHOUSE
SCRUBBER
INCINERATOR
FUEL
FEED
FURNACE
FORMING
CURING
PRODUCT
FUEL
BINDER

Figure A-4. Application of venturi scrubber.

Closed sections of mist eliminator should be opened to decrease air velocity, and freshwater wash used instead of contaminant-laden water wash.

Phase 2. Implementation

Install countercurrent nozzles.

Replace stainless steel nozzle tips with carbide tips.

Install impellers with abrasion-resistant plating.

Provide freshwater makeup for sump and mist eliminator spray nozzles.

Open appropriate mist eliminator sections.

Phase 3. Sampling and Testing

Opacity observations indicated 20 percent or less.

More conscientious preventive maintenance alleviated dust buildup and abrasion within operating components.

CASE HISTORY

PACKED TOWER SCRUBBER

INTRODUCTION

Odor complaints from local residents and in-plant employees were being received by a company that was refining precious metals (see Figure A-5). A countercurrent packed tower was being utilized to absorb the acid vapors emitted within numerous laboratory hoods. Occasionally, a plume was noticed that was attributed to the contaminant gas being condensed. The maintenance department checked the functioning components, and all seemed operational. It was then decided to recruit outside assistance to troubleshoot the program.

Phase 1. Problem Identification

Observations--

Plant under high negative pressure.

Hood velocity below Occupational Safety and Health Administration standard of 100 ft/min.

No evacuation slot at hood benchtop.

Hood exhaust ducts were not located properly to effect proper ventilation.

Packed tower nozzle orifices were partially clogged with plastic chips from the packing.

Pump impeller shaft broken.

Blower belt slippage.

Recommendations--

Increase makeup air to plant.

Extend hood baffle plate to benchtop and provide slot.

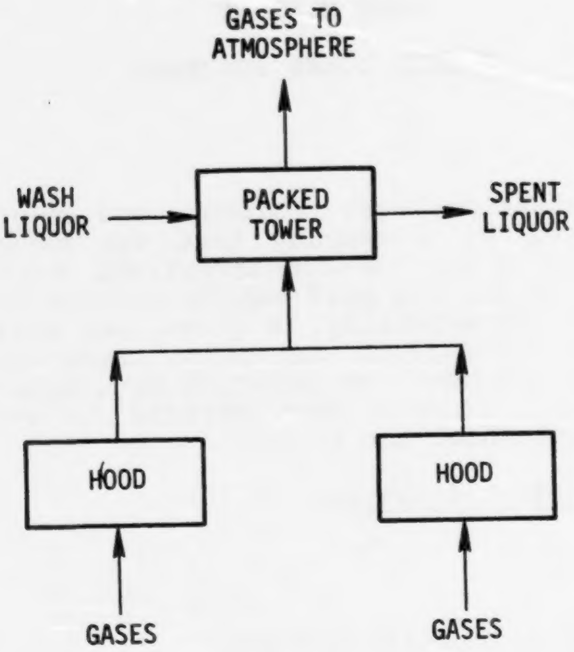
GASES TO ATMOSPHERE
WASH LIQUOR
PACKED TOWER
SPENT LIQUOR
HOOD
HOOD
GASES
GASES

Figure A-5. Application of packed tower scrubber.

Provide in-line strainers upstream of pump.

Replace impeller shaft.

Tighten pulley belts.

Phase 2. Implementation

Canvas makeup duct installed in two plant locations.

Fiberglass baffle plate extended to benchtop.

Strainer with holes slightly smaller than nozzle orifice installed.

Impeller shaft replaced.

New blower pulley belts installed.

Phase 3. Sampling and Testing

Hood face velocity measured at 100 ft/min.

Exhaust duct flowrate increased 30 percent.

No apparent odor at stack.